Biotechnology

Changing Life Through Science

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Biotechnology

Changing Life Through Science

Volume 1
Medicine

K. Lee Lerner and
Brenda Wilmoth Lerner, Editors

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Introduction

Biotechnology: Changing Life Through Science is devoted to helping younger students and general readers understand the fast-developing science and issues related to technologies touching on the most intimate and fundamental mechanisms of life.

This book is a collection of more than 165 entries on topics covering biotechnology applications ranging across medicine, agriculture, and industry. To be sure, the topics are often challenging to younger students—but in such challenges lie the opportunity to place their early studies of basic science into a context that both motivates them toward science and that enhances their critical thinking skills as they evaluate news and issues related to science, technology, and ethics.

Toward this goal, *Biotechnology: Changing Life Through Science* entries are designed to instruct, challenge, and excite less-experienced students, while providing a solid foundation and reference for students already captivated by biotechnology.

At the core of the advances in biotechnology lies the science of molecular biology and genetics. Because *Biotechnology: Changing Life Through Science* is designed for younger students, the editors have attempted to include simple explanations of sometimes advanced scientific principles. Despite the complexities of genetics, along with the fast pace of research and innovation, every effort has been made to set forth entries in everyday language and to provide generous explanations of the most important terms used by professional scientists.

Essential features of *Biotechnology: Changing Life Through Science*

Written by experts, teachers, and expert writers in fields of physics, molecular biology, genetics, and microbiology, every effort has been taken to explain scientific concepts clearly and simply, without sacrificing fundamental accuracy. The articles in the book are meant to be understandable by anyone with a curiosity about biotechnology.

Entries are arranged alphabetically within volumes devoted to applications generally (but not exclusively) related to biomedical, agricultural, and industrial biotechnologies. *See also* references at the end of entries alert the readers to related entries across the three-volume set that may provide additional resources or insights each topic.

Each entry contains a *Words to Know* section to help students understand important or complex terms. A general compendium of these terms is also included in the book. A *Timeline* allows students to place events in context to significant advances in science and biotechnology.

A *Where To Learn More* section lists generally usable print material and Web sites, while a comprehensive *General Index* guides the reader to topics and terms mentioned in the book.

Photos and color illustrations created for this title are included throughout the book where they might stimulate interest or understanding.

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K. Lee Lerner and Brenda Wilmoth Lerner, editors
London, U.K., and Cairo, Egypt
October 2006

K. Lee Lerner is a physicist, lecturer, and director of more than two dozen books and films related to science and technology. Brenda Wilmoth Lerner is former nurse and infection control expert who has edited or written more than a dozen books related to the history and applications of medical science.

Timeline

1947 Nuremberg Code issued regarding voluntary consent of human subjects.

1948 Barbara McClintock publishes her research on transposable regulatory elements ("jumping genes") in maize. Her work was not appreciated until similar phenomena were discovered in bacteria and fruit flies in the 1960s and 1970s. McClintock was awarded the Nobel Prize in Medicine or Physiology in 1983.

1952 Alfred Hershey and Martha Chase publish a paper suggesting that DNA (deoxyribonucleic acid) is the genetic material.

1952 Renato Dulbecco develops a practical method for studying animal viruses in cell cultures.

1952 Rosalind Franklin completes a series of x-ray crystallography studies of two forms of DNA. Her colleague, Maurice Wilkins, gives information about her work to James Watson.

1953 James D. Watson and Francis H. C. Crick publish two landmark papers in the journal *Nature*. Watson and Crick propose a double helical model for DNA and call attention to the genetic implications of their model. Their model is based, in part, on the x ray crystallographic work of Rosalind Franklin and the biochemical work of Erwin Chargaff. Their model explains how the genetic material is transmitted.

1953 Jonas Salk begins testing a polio vaccine comprised of a mixture of killed viruses.

1953 Stanley Miller produces amino acids from inorganic compounds similar to those in Earth's primitive atmosphere with electrical sparks that simulate lightning.

1955 Fred L. Schaffer and Carlton E. Schwerdt report on their successful crystallization of the polio virus. Their achievement is the first successful crystallization of an animal virus.

1955 National Institutes of Health organizes a Division of Biologics Control within the U.S. Food and Drug Administration (FDA), following deaths from a faulty polio vaccine.

1957 Alick Isaacs and Jean Lindenmann publish their pioneering report on the drug interferon, a protein produced by interaction between a virus and an infected cell that can interfere with the multiplication of viruses.

1957 Francis Crick proposes that during protein formation each amino acid is carried to the RNA template by an "adapter molecule" containing nucleotides and that the adapter is the part that actually fits on the RNA template. Later research demonstrates this "adapter molecule" is transfer RNA.

1958 FDA publishes its first list of substances generally recognized as safe.

1958 Frederick Sanger is awarded the Nobel Prize in chemistry for his work on the structure of proteins, especially for determining the primary sequence of insulin.

1958 George W. Beadle, Edward L. Tatum, and Joshua Lederberg were awarded the Nobel Prize in Medicine or Physiology. Beadle and Tatum were honored for the work with a group of fungi called *Neurospora* that led to the one gene-one enzyme theory. Lederberg was honored for discoveries concerning genetic recombination and the organization of the genetic material of bacteria.

1959 English biochemist Rodney Porter begins studies that lead to the discovery of the structure of antibodies. Porter receives the 1972 Nobel Prize in Physiology or Medicine for this research.

1959 Severo Ochoa and Arthur Kornberg are awarded the Nobel Prize in Medicine or Physiology for their discovery of the mechanisms in the biological creation (synthesis) of ribonucleic acid (RNA) and deoxyribonucleic acid (DNA).

1959 Sydney Brenner and Robert W. Horne develop a method for studying viruses using the electron microscope.

1961 Francis Crick, Sydney Brenner, and others propose that a molecule called transfer RNA uses a three-base code in the manufacture of proteins.

1961 Marshall Warren Nirenberg and J. Heinrich Matthaei establish the relationship between the sequence of nucleotides in the genetic material and amino acids in the gene product.

1962 United States Congress passes Kefauver-Harris Drug Amendments that shift the burden of proof of clinical safety to drug manufacturers. For the first time, drug manufacturers had to prove their products were safe and effective before they could be sold.

1965 Anthrax vaccine adsorbed (AVA), is approved for use in the United States.

1965 François Jacob, André Lwoff, and Jacques Monod are awarded the Nobel Prize in Medicine or Physiology for their discoveries concerning genetic control of enzymes and virus synthesis.

1965 James M. Schlatter, American chemist, combines two amino acids and obtains a sweet-tasting substance. This chemical is about 200 times sweeter than sugar and is named aspartame. In 1983, it is approved for use in carbonated beverages. It becomes a widely used artificial sweetener.

1966 Bruce Ames develops a test to screen for compounds that cause mutations, including those that are cancer causing. The so-called Ames test utilizes the bacterium *Salmonella typhimurium*.

1966 Marshall Nirenberg and Har Gobind Khorana lead teams that decipher the genetic code. All of the 64 possible triplet combinations of the four bases (the codons) and their associated amino acids are determined and described.

1967 Charles Yanofsky demonstrates that the sequence of codons in a gene determines the sequence of amino acids in a protein.

1967 Thomas Brock discovers the heat-loving bacterium *Thermus aquaticus* from a hot spring in Yellowstone National Park. The bacterium yields the enzyme that becomes the basis of the DNA polymerase reaction.

1968 Werner Arber discovers that bacteria defend themselves against viruses by producing DNA-cutting enzymes. These enzymes quickly become important tools for molecular biologists.

1969 By executive order of the President, the United States renounces first-use of biological weapons and restricts future weapons research programs to issues concerning defensive responses (e.g., immunization, detection, etc.).

1969 Jonathan R. Beckwith, American molecular biologist, and colleagues isolate a single gene.

1969 Max Delbrück, Alfred D. Hershey, and Salvador E. Luria are awarded the Nobel Prize in Medicine or Physiology for their discoveries concerning the replication mechanism and the genetic structure of viruses.

1970 Howard Martin Temin and David Baltimore independently discover reverse transcriptase in viruses. Reverse transcriptase is an enzyme that speeds the reaction in which RNA can be transcribed into DNA.

1972 Biological and Toxin Weapons Convention first signed. BWC prohibits the offensive weaponization of biological agents (e.g., anthrax spores). The BWC also prohibits the transformation of biological agents with established legitimate and sanctioned purposes into agents of a nature and quality that could be used to effectively induce illness or death.

1972 Paul Berg and Herbert Boyer produce the first recombinant DNA molecules by splicing together pieces of DNA from different sources to form recombinant genes. Recombinant technology emerges as one of the most powerful techniques of molecular biology.

1973 Concerns about the possible hazards posed by recombinant DNA technologies, especially work with tumor viruses, leads to the establishment of a meeting at Asilomar, California. The proceedings of this meeting are subsequently published by the Cold Spring Harbor Laboratory as a book entitled *Biohazards in Biological Research.*

1975 César Milstein and George Kohler create monoclonal antibodies, which are explored as drug treatments for cancer and other diseases.

1977 Frederick Sanger develops a method to sequence the genome of a microorganism.

1977 The first known human fatality from H5N1 avian flu (bird flu) occurs in Hong Kong.

1977 The last reported smallpox case is recorded. Ultimately, the World Health Organization (WHO) declares the disease eradicated.

1978 Louise Brown, the world's first "test-tube baby," is born.

1978 Scientists clone the gene for human insulin.

1980 Researchers successfully introduce a human gene, which codes for the protein interferon, into a bacterium.

1981 AIDS (acquired immune deficiency syndrome) is recognized and tracked as an epidemic.

1983 *Escherichia coli* O157:H7 is identified as a human pathogen.

1983 Luc Montagnier and Robert Gallo discover the human immunodeficiency virus that is believed to cause acquired immunodeficiency syndrome.

1983 The United States Congress passes the Orphan Drug Act, which allowed the FDA to research and market drugs necessary for treating rare diseases.

1985 Alec Jeffreys develops "genetic fingerprinting," a method of using DNA polymorphisms (unique sequences of DNA) to identify individuals. The method, which has been used in paternity, immigration, and murder cases, is generally referred to as "DNA fingerprinting."

1987 Maynard Olson creates and names yeast artificial chromosomes (YACs), which provided a technique to clone long segments of DNA.

1987 The idea to use patterns of the iris of the eye as an identification marker was patented, along with the algorithms necessary for iris identification.

1988 The Human Genome Organization (HUGO) is established by scientists in order to coordinate international efforts to sequence the human genome. The Human Genome Project officially adopts the goal of determining the entire sequence of DNA comprising the human chromosomes.

1989 Sidney Altman and Thomas R. Cech are awarded the Nobel Prize in chemistry for their discovery of ribozymes (RNA molecules with catalytic activity). Cech proves that RNA could function as a biocatalyst as well as an information carrier.

1989 The Internet revolution begins with the invention of the World Wide Web.

1991 The gender of a mouse is changed at the embryo stage.

1992 American and British scientists develop a technique for testing embryos in the womb for genetic abnormalities such as cystic fibrosis and hemophilia.

1993 George Washington University researchers clone human embryos and nurture them in a Petri dish for several days. The project provokes protests from ethicists, politicians, and critics of genetic engineering.

1994 Geneticists determine that DNA repair enzymes perform several vital functions, including preserving genetic information and protecting the cell from cancer.

1994 The Genetic Privacy Act, the first United States Human Genome Project legislative product, proposed regulation of the collection, analysis, storage, and use of DNA samples and genetic information obtained from them.

1995 After thwarting U.N. weapons inspectors, the government of Iraq admits to producing over 200 gallons (8,000 liters) of concentrated anthrax as part of the nation's biological weapons program.

1995 Religious leaders and biotechnology critics protest the patenting of plants, animals, and human body parts.

1996 Dolly, the world's first cloned sheep, is born. Several European countries ban human cloning. U.S. Congress debates a bill to ban human cloning.

1996 H5N1 avian flu virus is identified in Guangdong, China.

1996 Researchers C. Cheng and L. Olson demonstrate that the spinal cord can be regenerated in adult rats. Experimenting on rats with a severed spinal cord, Cheng and Olson use peripheral nerves to connect white matter and gray matter.

1996 Scientists discover a link between apoptosis (cellular suicide, a natural process whereby the body eliminates useless cells) gone awry and several neurodegenerative conditions, including Alzheimer's disease.

1997 Ian Wilmut of the Roslin Institute in Edinburgh, Scotland, announces the birth of a lamb called Dolly, the first mammal cloned from an adult cell (a cell in a pregnant ewe's mammary gland).

1997 Microscopic analysis of the Murchison meteorite led some scientists to argue evidence of ancient life on other planets.

Later studies cast doubt that the changes in the meteorite must be due to biological processes.

1997 Researchers identify a gene that plays a crucial role in establishing normal left-right configuration during organ development.

1997 The National Center for Human Genome Research (NCHGR) at the National Institutes of Health becomes the National Human Genome Research Institute (NHGRI).

1997 While performing a cloning experiment, Christof Niehrs, a researcher at the German Center for Cancer Research, identifies a protein responsible for the creation of the head in a frog embryo.

1997 William Jacobs and Barry Bloom create a biological entity that combines the characteristics of a bacterial virus and a plasmid (a DNA structure that functions and replicates independently of the chromosomes).

1998 DNA fingerprinting is used to identify remains of Russian Imperial Romanov family.

1998 The U.S. Department of Energy (DOE) funds bacterial artificial chromosome and sequencing projects.

1998 Dolly, the first cloned sheep, gives birth to a lamb that had been conceived by a natural mating with a Welsh Mountain ram. Researches said the birth of Bonnie proved that Dolly was a fully normal and healthy animal.

1998 Ian Wilmut announced the birth of Polly, a transgenic lamb containing human genes.

1998 Immunologist Ellen Heber-Katz, researcher at the Wistar Institute in Philadelphia, reports that a strain of laboratory mice can regenerate tissue in their ears, closing holes which scientists had created for identification purposes. This discovery reopens the discussion on possible regeneration in humans.

1998 Two research teams succeed in growing embryonic stem cells.

1999 Scientists announce the complete sequencing of the DNA making up human chromosome 22. The first complete human chromosome sequence is published in December 1999.

2000 On June 26, 2000, leaders of the public genome project and Celera, a biotech company, announce the completion of a working draft of the entire human genome sequence.

2000 U.S. President Clinton signed an executive order prohibiting federal departments and agencies from using genetic information in hiring or promoting workers.

2000 The first volume of *Annual Review of Genomics and Human Genetics* is published. Genomics is defined as the new science dealing with the identification and characterization of genes and their arrangement in chromosomes. It defines human genetics as the science devoted to understanding the origin and expression of human individual uniqueness.

2001 In February 2001, the complete draft sequence of the human genome is published. The public sequence data is published in the British journal *Nature*, and the Celera sequence is published in the American journal *Science*. Increased knowledge of the human genome allows greater specificity in pharmacological research and drug interaction studies.

2001 Letters containing a powdered form of *Bacillus anthracis*, the bacteria that causes anthrax, are mailed by an unknown terrorist or terrorist group (foreign or domestic) to government representatives, members of the news media, and others in the United States. More than 20 cases and five deaths are eventually attributed to the terrorist attack.

2001 The company Advanced Cell Technology announces that its researchers have created cloned human embryos that grew to the six-cell stage.

2001 The United States announces that the National Institutes of Health (NIH) will fund research on only 64 embryonic stem cell lines already created from human embryos.

2002 Following September 11, 2001, terrorist attacks on the United States, the Public Health Security and Bioterrorism Preparedness and Response Act of 2002 is passed in an effort to improve the ability to prevent and respond to public health emergencies.

2002 Severe acute respiratory syndrome (SARS) virus is found in patients in China, Hong Kong, and other Asian countries. The newly discovered virus is not identified until early 2003. The spread of the virus reaches epidemic proportions in Asia and expands to the rest of the world.

2002 The agricultural chemical atrazine, used in weed control, is thought to be partially responsible for the dramatic global decline in amphibians, as it is found to disturb male frog sex hormones, altering their reproductive organs.

2002 The Best Pharmaceuticals for Children Act is passed in an effort to improve safety and efficacy of patented and off-patent medicines for children.

2002 The Defense Advanced Research Projects Agency (DARPA) initiates the Biosensor Technologies program in 2002 to develop fast, sensitive, automatic technologies for the detection and identification of biological warfare agents.

2002 The planned destruction of stocks of smallpox-causing variola virus at the two remaining depositories in the United States and Russia is delayed over fears that large-scale production of vaccine might be needed in the event of a bioterrorist action.

2003 "Smart passports" fitted with a microchip that will allow immigration officials to identify the facial biometric features of the passport holder are under development and scheduled for introduction by early 2005.

2003 FDA requires food labels to include trans fat content. Trans fats are believed to raise cholesterol levels in the blood. This is the first major change to the nutrition facts panel on foods since 1993.

2003 Dolly, the first cloned sheep, dies of a chronic lung disease.

2003 United States invades Iraq and finds chemical, biological, and nuclear weapons programs, but no actual weapons.

2004 Food Allergy Labeling and Consumer Protection Act requires the labeling of food containing a protein derived peanuts, soybeans, cow's milk, eggs, fish, crustacean shellfish, tree nuts, and wheat that accounts for a majority of food allergies.

2004 Project BioShield Act of 2004 authorizes U.S. government agencies to expedite procedures related to rapid distribution of treatments as countermeasures to chemical, biological, and nuclear attack.

2005 U.S. FDA Drug Safety Board is founded.

2006 Mad cow disease confirmed in Alabama cow as third reported case in the United States.

2006 H5N1 virus, responsible for avian flu, spreads from Asia to Europe. The World Health Organization (WHO) attempts to coordinate multinational disaster and containment plans. Some nations begin to stockpile antiviral drugs.

2006 U.S. Center for Biologics Evaluation and Research (CBER) launches a new Genetic Modification Clinical Research Information System (GeMCRIS)—an Internet database related to human gene transfer trials. The database allows access to information about human gene transfer research.

Words To Know

A

Acidic: Having the qualities of an acid, one of which is that it will chemically react with and neutralize metallic oxides.

Acquired immune deficiency syndrome (AIDS): An epidemic disease caused by an infection with the human immunodeficiency virus (HIV).

Acromegaly: A disease caused by the release of excess growth hormone, resulting in excessive growth of some bones.

Adhesive: A substance that causes a physical attraction between different types of molecules; glue.

Adrenal glands: Two glands located next to the kidneys. The adrenal glands produce the hormones epinephrine and norepinephrine and the corticosteroid hormones.

Adult stem cell: A renewable and unspecialized cell found among specialized cells in a tissue or organ.

Aerobic reaction: Chemical reaction that requires oxygen or that take place in the presence of oxygen.

Aerodynamics: The study of forces associated with air moving over airfoil shapes (airplane or bird wings).

Algae: A group of tiny aquatic plants (including seaweed and pond scum) with chlorophyll and colored pigments.

Alkali: A water-soluble material (a material that can be dissolved in water) that comes from ash after plant material or wood is burned.

Allele: Any of two or more alternative forms of a gene that occupy the same location on a chromosome.

Allogenic: Of the same species.

Allograft: Transplanted tissues or organs from donors of the same species.

Alzheimer's disease: A degenerative disease of the central nervous system that generally afflicts elderly people and that can lead to memory loss and death.

Amino acids: Compounds whose molecules are one of the building blocks of a protein.

Ammonia: A chemical composed of molecules containing one nitrogen and three hydrogen atoms.

Amniocentesis: A method of detecting genetic abnormalities in a fetus; in this procedure, amniotic fluid is sampled through a needle placed in the uterus; fetal cells in the amniotic fluid are then analyzed for genetic defects.

Amniotic fluid: The fluid that surrounds the developing fetus in the womb.

Amputate: To cut off a limb or part of the body.

Anabolic: To build the body. Often used to describe a group of hormones sometimes abused by athletes in training to temporarily increase the size of their muscles.

Anaerobic reaction: Chemical reaction that takes place in the absence of oxygen.

Analgesic: A drug that relieves pain without loss of consciousness.

Anaphylactic shock: A violent, sometimes fatal, response to an allergen after initial contact.

Anesthesia: A drug that induces sleep so that an individual can undergo surgery or remain unconscious until a crucial and painful period of a surgical procedure has passed.

Anode: A positively charged electrode.

Antennae: Small sensory projections on the front section of the head of insects and other animals.

Anthrax: A deadly disease caused by anthrax bacteria. Used more often as a biological weapon than any other bacterium or virus.

Antibacterial: A substance that kills or inhibits the growth of germs (bacteria and other microorganisms, but not viruses). Also often a term used to describe a drug used to treat bacterial infections.

Antibiotics: Drugs that target and kill bacteria, but are ineffective against viruses.

Antibodies: Molecules created by the immune system in response to the presence of an antigen (a foreign substance or particle). Antibodies mark foreign microorganisms in the body for destruction by other immune cells.

Anticoagulant: A subtance that prevents blood from clotting.

Antifreeze protein: In nature, antifreeze proteins (AFPs) help animals and plants living in extreme winters cope with extreme cold. AFPs prevent formation of ice crystals so the fluids within an organism do not freeze.

Antifreeze: A substance that lowers the freezing temperature.

Antigen: A molecule, usually a protein, that the body identifies as foreign and toward which it directs an immune response.

Antimicrobial: A material that slows the growth of bacteria or that is able to to kill bacteria. Includes antibiotics (which can be used inside the body) and disinfectants (which can only be used outside the body).

Antioxidant: A chemical compound that has the ability to prevent the oxidation of substances with which it is associated. Oxidation can damage cells.

Apoptosis: Programmed cell death in which a controlled sequence of events (or program) leads to the elimination of cells without releasing harmful substances into the surrounding area. Many types of cell damage can trigger apoptosis, and it also occurs normally during development.

Arrhythmia: Any abnormal rhythm of the heart, which can be too rapid, too slow, or irregular in pace; one of the symptoms of anxiety disorder.

Arthritis: Inflammation of the joints.

Artificial insemination: The process of placing male sperm into the reproductive tract of the female to increase the chances of fertilization. AI is one of the treatments for infertility among humans. With animals, AI is used as a means of producing superior offspring by selecting healthy parents with desired traits.

Artificial intelligence: Devices that attempt to reproduce or exhibit human-like intelligence and behavior.

Artificial selection: Selective breeding, carried out by humans, to produce desired traits in domestic animals and plants.

Aspartame: A low-calorie artificial (synthetic) sweetener.

Atherosclerosis: Abnormal narrowing of the arteries of the body that generally originates from the buildup of fatty plaque on the artery wall.

Atom: Small, indestructible particles, composed of protons, neutrons, and electrons, from which all elements are made.

Autograft: A type of skin graft that uses tissue from another part of the patient's own body, and therefore has cells with the same genes.

Autoimmune disorder: Disorders that are caused by misdirected immune response in which lymphocytes mount an attack against normal body cells.

Autologous: A transfusion or transplant of a patient's own blood, bone marrow, or tissue.

Autologous blood transfusion: A transfusion from a patient's own blood.

B

Bacteria: Microscopic, usually one-celled, organisms whose activities range from the development of disease to fermentation.

Bacterial resistance: Immunity evolved by a certain strain of bacteria to one or more antibiotics.

Bacterium: (Singular of bacteria.) A single-celled microorganism that is often parasitic.

Base pair: Two bases bonded together—either A with T, or C with G—to bridge the two spirals of a DNA molecule, much as a rung connects the two uprights of a ladder.

Base: One of the four chemical letters in the DNA code. There are four kinds, called A, C, G, and T (short for adenine, cytosine, guanine, and thymine).

Batik: A method of dyeing cloth in which areas are covered with substances that keep dyes from penetrating in order to make patterns.

Benign: A growth that does not spread to other parts of the body. Recovery is favorable with treatment.

Bioactive: An artificial material that has an effect on a natural, living organism, cell, or tissue.

Bioballistic method: The shooting of tiny DNA-coated metal bullets into cells as part of the genetic engineering process.

Biochemist: A scientist who studies biochemistry (the study of the molecules and chemical reactions in living things).

Biocompatible: Able to live or exit together. Not harmful or mutually beneficial.

Biodegradable: Able to be broken down by natural processes.

Biodetectors: Devices that can detect biological molecules and substances.

Biodiesel: An environmentally friendly fuel made from a combination of plant and animal fat. It can be safely mixed with petro diesel.

Biodiversity: Literally, "life diversity": the number of different kinds of living things. The more different kinds, the greater the biodiversity.

Bioengineered: The process of using engineering to solve medical problems.

Biofortify: To genetically engineer a crop plant so that it produces more of a certain nutrient, such as iron or a vitamin.

Biogas: Methane produced by rotting excrement or other biological sources. It can be burned as a fuel.

Biological and Toxic Weapons Convention: Treaty dating to the early 1970s that forbids the use of biological weapons.

Biological weapon: A weapon that uses bacteria, viruses, or poisonous substances made by bacteria or viruses.

Biologist: A scientist who studies biology (the science of living things).

Biomass: Any biological material used to produce energy (such as wood by burning).

Biometrics: Computerized identification of persons using traits or behaviors that are unique to each individual.

Biopharming: The practice of growing genetically engineered plants or animals to produce chemicals that can be used as drugs.

Bioprocessing: The use of microorganisms to produce a desired end product.

Bioreactor: A container used for bioprocessing.

Bioremediation: The use of living organisms to help repair environmental damage, such as from an oil spill.

Biorobotics: The use of living organisms to create or modify robots or robotic devices.

Biosafety: The safe handling of bacteria and viruses. Four levels of biosafety are officially defined for laboratories that handle bacteria and viruses.

Biosafety cabinet: A box in which biological laboratory work may be done safely. It either sucks air in to keep germs from escaping, or is completely sealed against the outside air.

Biosynthesis: Production of a chemical compound by a living organism, as in metabolism.

Biotechnology: Any technique that uses parts of living organisms to create or modify products, plants, animals, or microorganisms for specific uses.

Bioterrorism: Terrorism using biological weapons such as bacteria or viruses.

Blastocyst: A cluster of cells resulting from multiple cell divisions after successful fertilization of an ovum by a sperm. This is the developmental form that must implant itself in the uterus to achieve pregnancy.

Bone marrow: A spongy tissue located in the hollow centers of certain bones, such as the skull and hip bones. Bone marrow is the site of blood cell generation.

Bone: Composed primarily of a non-living matrix of calcium salts and a living matrix of collagen fibers, bone is the major component that makes up the human skeleton. Bone produces blood cells and functions as a storage site for elements such as calcium and phosphorus.

Brackish: A mixture of fresh and salt water.

Bradycardia: A heartbeat that is too slow.

Bronchodilators: Drugs, either inhaled or taken orally, that widen lung airways by relaxing the chest muscles.

Bt: Short for *Bacillus thuringiensis*, a kind of bacteria. Genes from Bt bacteria have been added to the DNA of some genetically engineered plants, including corn and cotton, to make them resistant to certain insects.

C

Cadaver: A dead body.

Calcium: An essential macro mineral necessary for bone formation and other metabolic functions.

Calorie: The amount of energy obtained from food. The number of calories needed daily is based on a person's age, gender, weight, and activity level.

Cambium: A layer of actively dividing cells in plants, from which tissues used for conducting water and nutrients are derived.

Carbohydrates: Carbon-containing compounds that form the supporting tissues of plants. Found in abundance in foods made from grains.

Carbon dioxide: A heavy, colorless gas that dissolves in water.

Carbonation: Bubbling in a liquid caused by carbon dioxide.

Cardiac: Having to do with the heart.

Cartilage: A connective tissue found in the knees, tip of the nose, and outside of the ears; it provides flexibility and resilience to these structures.

Catabolic: To break down. The break down of complex molecules into simpler molecules.

Catalyst: Any agent that accelerates a chemical reaction without entering the reaction or being changed by it.

Catalyze: To accelerate a chemical reaction without entering the reaction or being changed by it.

Cathode: A negatively charged electrode.

Cell line: Series of cells descended from each other like the generations of a family.

Cells: The smallest living units of the body which together form tissues.

Cellulose: The main ingredient of plant tissue and fiber.

Cellulosic fermentation: The production of ethanol by the fermentation of cellulose rather than of starches and sugars.

Centers for Disease Control: Department of the U.S. government devoted to understanding and preventing the spread of infectious disease. Often referred to as the CDC.

Ceramic: A hard, brittle substance produced by strongly heating a nonmetallic mineral or clay.

Chemotherapy: Use of powerful drugs to kill cancer cells in the human body.

Chlorophyll: Green pigment in a plant leaf that is involved in the process of photosynthesis.

Cholesterol: A common type of steroid in the body, which is made in the liver. High levels are associated with cardiovascular disease.

Chorionic villus sampling: Testing a sample of cells from the tissue surrounding the embryo. It can be used to determine a child's paternity before he or she is born.

Chromosome: A thread-shaped structure that carries genetic information in cells.

Circumcision: Removal of the foreskin of the penis.

Clinical trial: A government-approved experiment using human volunteers to see if a new drug or other treatment for a disease is safe and effective.

Clone: A cell or organism which contains the identical genetic information of the parent cell or organism.

Cloning: The production of multiple genetically identical cells or organisms.

Clotting: The solidification of blood in response to a wound: coagulation.

Coagulation: The solidifying or clotting of blood. Beneficial when used by the body to seal a wound; harmful if it occurs inside blood vessels.

Cocklebur: A flowering plant whose seeds are produced in a spiny, double-chambered burr.

Coding sequence: A gene that produces a protein when triggered by a promoter gene.

Collagen: A type of protein that makes up connective tissue in the body.

Combination therapy: The use of more than one drug at the same time in treating a disease. Combination therapy is standard in both AIDS and cancer.

Complementary DNA: DNA that is created (transcribed) from an RNA template. This is the reverse of the normal process and so is called reverse transcription.

Compost: A mixture of decaying organic matter, such as manure and leaves, that can be used as fertilizer.

Cortisol: A hormone involved with reducing the damaging nature of stress.

Cosmetic: Preparation or procedure intended for beautifying the body.

C-reactive protein: A protein which is released during inflammation. Used as a measure of risk for heart attack and stroke.

Crop: Agricultural plant grown on a farm. Also: part of an ant's digestive tract that expands to form a sac in which liquid food is stored.

Cross-pollination: Transport of pollen from the flower of one plant to the flower of a different plant of the same species.

Cryonic suspension: Storing or preserving organisms (or parts of organisms) at very low temperatures.

Cryonicists: Scientists who study cryonics, the science of storing or preserving organisms (or parts of organisms) at very low temperatures.

Culture medium: A substance that supports the growth of bacteria so they may be identified.

Curdle: To coagulate milk (create curds) with acidic substances.

Curds: The lumps obtained by the mixing and coagulating milk with acidic substances and then draining off the liquid (whey).

Cushing syndrome: A disorder in which too much of the adrenal hormone, cortisol, is produced; it may be caused by a pituitary or adrenal gland tumor.

Custody: The legal right of a parent to care for and make decisions regarding their child.

Cystic fibrosis: A fatal disease in which a single defective gene prevents the body from making a protein called cystic fibrosis transmembrane conductance regulator.

Cytokine: Molecule produced by cells to control reactions between other cells.

D

Database: A collection of data in a computer.

Dead zone: An area of ocean where nothing can live except bacteria that flourish on fertilizer from agricultural runoff.

Defoliation: Removal of leaves from a tree.

Deforestation: Removal of trees from an area.

Deoxyribonucleic acid (DNA): The double-helix shaped molecule that serves as the carrier of genetic information for humans and most other organisms.

Dermis: The innermost layer of skin. It is made up of connective tissue that gives skin its strength.

Desiccation: The process of removing water; drying out.

Dextrose: A naturally occurring form of glucose. Also one of the two main sugars found in honey.

Diabetes: A disease in which the body cannot make or properly use the hormone insulin.

Dialysis: The mechanical filtering of blood to replace the functioning of kidneys or liver.

Diesel engine: An internal combustion engine that burns diesel oil as fuel.

Differentiate: To become a specialized type of cell.

Diffusion: Random movement of molecules which leads to a net movement of molecules from a region of high concentration to a region of low concentration.

Digital: Information processed as encoded on or off data bits.

Distill: Collecting and condensing the vapor from a boiling solution. Each distinct, volatile chemical compound boils off individually at a specific temperature, so distillation is a way of purifying the volatile compounds in a mixture.

DNA (deoxyribonucleic acid): A double-helix shaped molecule inside cells that holds the genetic information.

DNA polymerase: A chemical that turns a single-sided piece of DNA into a double-sided piece (if nucleotides are available in the solution). Found in nature and used in the polymerase chain reaction (PCR).

DNA sequence: The sequence of base pairs in a DNA molecule.

DNA template: In the polymerase chain reaction used to copy DNA, the DNA template is the piece of DNA that is to be copied.

Drought: A prolonged and abnormal shortage of rain.

E

Ecosystem: A group of organisms and the environment they inhabit.

Elastomer: An organic polymer that has rubber-like, elastic qualities.

Electric field: An invisible physical influence that exerts a force on an electric charge. All electric charges produce electric fields. Magnetic fields that are changing (getting weaker or stronger) also produce electric fields.

Electricity: An electric current produced by the repulsive force produced by electrons of the same charge.

Electrochemical: The study of chemical change involving electricity.

Electrode: A conductor by which electricity enters or leaves.

Electrolyte: A chemical compound that separates into ions (charged particles) in a solution and is then able to conduct electricity.

Electron: A fundamental particle of matter carrying a single unit of negative electrical charge.

Electrophoresis: Separation of nucleic acid or protein molecules in an electric field.

Elements: Pure substances that cannot be changed chemically into a simpler substance.

Embryo: A stage in development after fertilization of an egg by a sperm.

Embryologist: A scientist who studies embryos and their development.

Embryonic stem cell: A stem cell found in embryos about a week old. Descendants of one of these cells can be any kind of tissue. These cells can reproduce indefinitely in the laboratory.

Emissions: The generation of photons of light from an electronically excited atomic or molecular species in order to reduce its total energy.

Encryption: The converting of text into difficult-to-understand code so that it is only readable by specific people.

Enteric: Involving the intestinal tract or relating to the intestines.

Enzymes: Proteins that help control the rate or speed of chemical reactions in the cell.

Epidermis: The outer layer of the skin consisting of dead cells. It is the primary protective barrier against sunlight, chemicals, and other possible harmful agents. The epidermal cells are constantly being shed and replenished.

Epithelium: The layer of cells that covers external and internal surfaces of the body. The many types of epithelium range from flat cells to long cells to cubed cells.

***Escherichia coli*:** *E. coli*, a species of bacteria that live in the intestinal tract and that are often associated with fecal contamination.

Essential acid: Acids that cannot be synthesized by the body and must be obtained from the diet.

Ethanol: A type of alcohol having different forms that can be drunk or used as fuel.

Ethical: Having to do with morality, or what is perceived as being the right thing to do.

Ethics: The study of what is right or wrong.

Ethyl alcohol: A drinkable alcohol, also called ethanol, which is produced by the fermentation of sugar.

Ethylene: A gas used to make tomatoes ripen quickly.

Eugenics: A social movement in which the population of a society, country, or the world is to be improved by controlling the passing on of hereditary information through selective breeding.

Eukaryotes: Cells whose genetic material is carried on chromosomes inside a nucleus encased in a membrane. All organisms except bacteria are eukaryotes.

Evolution: In biology, inheritable changes occurring over a time span greater than one generation.

***Ex situ*:** A Latin term meaning "from the place" or removed from its original place.

Expression (of gene): In cell biology, to make a protein according to the recipe in a DNA molecule. A gene that is used to make a protein is said to be expressed.

Extraterrestrial: Beyond Earth.

F

Fat substitute: A substance that feels like fat or help foods feel like they contain fat.

Fats: Waxy or oily substances found in many plant and animals tissues. An oil is a fat that is liquid at room temperature.

Fatty acid: An acid made of carbon, hydrogen, and oxygen that is found in body fat.

Feces: Solid waste of a living body.

Feedstock: The source of starting material for a chemical reaction.

Fermentation: The process of breaking down sugar without oxygen into simpler substances, commonly alcohol and carbon dioxide.

Fertilizer: An agricultural chemical that is added to soil to provide nutrients and increase crop productivity.

Fibrin: A protein that functions in the blood-clotting mechanism; forms mesh-like threads that trap red blood cells.

Fibroblast cells: Cells in the dermis layer of the skin that give rise to connective tissue.

Fixative: A substance used to bind dye to a fabric.

Fluorescence: Emission of light at one wavelength in response to light at another wavelength. For example, a substance that glows visibly when exposed to ultraviolet light is fluorescing.

Fossil fuel: A fuel that is derived from the decay of plant or animal life; coal, oil, and natural gas are the fossil fuels.

Fouling: A term to describe the buildup of organisms (plants, algae, small animals, etc.) on a ship's hull, slowing its speed.

Free radical: An unstable particle that can cause damage in cells.

G

Gel electrophoresis: A laboratory test that separates molecules based on their size, shape, or electrical charge.

Gene gun: A device that shoots tiny metal bullets coated with DNA fragments into cells in order to alter their DNA permanently.

Gene therapy: Treating disease by replacing nonfunctional genes or supplying genes that do function properly.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Gene use restriction technology (GURT): A form of genetic engineering that allows traits in plants to be turned on or off using chemicals or other means. Terminator technology is a form of GURT.

Genetic discrimination: The denial of rights or privileges to people because of the nature of their genes (DNA).

Genetic disease: An inherited disease.

Genetic disorder: An inherited disorder.

Genetic engineering: The manipulation of genetic material to produce specific results in an organism.

Genetic mutation: A change in the genes caused by a random change in the base sequence. This results in a trait not seen in either parent.

Genetic screening: Examination of a person's genes to see if they contain any tendencies for disease or other defects.

Genetically modified food: A food product that contains a genetically modified plant or animal as an ingredient.

Geneticist: A scientist who studies genes.

Genetics: The science of genes and heredity.

Genome: A complete set of the DNA for a species.

Genotropin: An artificial form of human growth hormone made in a laboratory.

Germ cell: A cell that can pass its DNA on to future generations, including egg and sperm cells.

Germline cells: Cells that can pass their DNA on to future generations, including egg and sperm cells.

Germline gene therapy: The introduction of genes into reproductive cells or embryos to correct inherited genetic defects that can cause disease.

Gigantism: A rare disease caused by the release of too much growth hormone while a child is still developing.

Glass: A ceramic material consisting of a uniformly dispersed mixture of silica, soda ash, and lime; and often combined with metallic oxides.

Global warming: A projected increase in Earth's surface temperature caused by an increase in the concentration of greenhouse gases, which absorb infrared energy emitted by Earth's surface, thereby slowing its rate of cooling.

Glucose: A simple sugar that exists in plant and animal tissues. When it occurs in blood, it is known as blood sugar.

Gluten: A mass of waste protein obtained from wheat or corn that is used as a raw material for producing MSG.

Glycolysis: A set of reactions in living organisms that use sugars and produce ATP, a molecule that provides cellular energy.

Glyphosate: A weed-killing chemical; the world's most-used herbicide.

Golden Rice: A kind of genetically engineered rice that is yellow because it contains substances that the body can use to make vitamin A.

Graft: A transplanted tissue.

Grafting: A method of propagation of woody plants whereby a shoot, known as a scion, is taken from one plant and inserted into a rootstock of another plant. Plants with the desired traits of the scion can be readily and quickly developed.

Gram-negative: Those cells that lose the color of the stain after they are washed with an alcohol solution during the staining process.

Gram-positive: Those cells that retain the color of the stain after they are washed with an alcohol solution during the staining process.

Greenhouse gas: A gas that contributes to the warming of the Earth's atmosphere. Examples include carbon dioxide, HCFCs, CFCs, and HFCs.

Growth hormone deficiency: A condition in which the body makes too little growth hormone.

H

Haplotype: A group of genes that are inherited together by some people.

Heart attack: Blockage of an artery bringing blood to part of the heart. May injure or kill part or all of the heart.

Hematopoietic cell: A cells in the bone marrow that gives rise, by splitting, to all the various kinds of blood cells. *Hemato-* means blood and *-poietic* means making.

Hemodialysis: A method of mechanically cleansing the blood outside of the body, used when an individual is in relative or complete kidney failure, in order to remove various substances which would normally be cleared by the kidneys.

Hemophilia: A genetic disorder in which one or more clotting factors are not released by the platelets; causes severe bleeding from even minor cuts and bruises.

Hepatitis: General inflammation of the liver; may be caused by viral infection or by excessive alcohol consumption.

Herbicide: A chemical substance used to kill weeds or undesirable plants.

HIV: Human immunodeficiency virus, the virus that causes AIDS (acquired immune deficiency syndrome).

Hormone: A chemical messenger produced by the body. Hormones are created by one organ of the body, but they usually carry out functions in other organs or parts of the body.

Horticulturalist: A person whose job it is to grow plants in a garden or greenhouse.

Human Genome Project: The joint project for designed to decode the entire human genome (hereditary information).

Human immunodeficiency virus (HIV): The virus that causes AIDS (acquired human immunodeficiency syndrome).

Human leukocyte antigens (HLA): A type of antigen present on white blood cells; divided into several distinct classes; each individual has one of these distinct classes present on their white blood cells.

Hybridize: When two lengths of a one-sided DNA molecule with mirror-matching codes lock or zip together to form a single piece of two-sided DNA, they are said to hybridize.

Hydrogenation: A chemical reaction in which hydrogen is added to a compound.

Hygroscopic: A compound which has a tendency to absorb water molecules.

Hypertension: High blood pressure.

I

Immune rejection: Immune system rejection of a foreign substance, such as a donated organ.

Immune system: A system in the human body that fights off foreign substances, cells, and tissues in an effort to protect a person from disease.

Immunosensor: Drugs or radiation used to reduce the immune system's ability to function.

Immunosuppression: The act of reducing the efficiency of the immune system.

Immunosuppressive drugs: Medicines that turn off the body's defense (immune) system. They are used to fight organ transplant rejection.

***In situ*:** A Latin term meaning "in place" or in the body or other natural system.

In vitro fertilization: Combining an egg and a sperm in the laboratory to create an embryo that is then implanted in the mother's uterus.

Incinerator: An industrial facility used for the controlled burning of waste materials.

Inflammation: A complex series of events associated with injury or disease that, when combined, serve to isolate, dilute, or destroy the agent responsible and the injured tissue.

Inorganic: Composed of minerals that are not derived from living plants and animals.

Insect resistance: The ability, possessed by some kinds of genetically engineered plants, to make a substance that is poisonous to insects.

Insecticide: A chemical that kills insects. Used in agriculture to kill insects that eat crops.

Insulin: A substance made by the body (or by genetically engineered bacteria) that the body needs to regulate the amount of sugar in the blood.

Insulin-like growth factor: A substance called IGF-1 for short, that is found in milk. More IGF-1 is found in milk from cows treated with recombinant bovine growth hormone and may increase the rate of twin births in women who drink such milk.

Interferon: A chemical messenger (cytokine) that plays a role in immune response.

Ion: An atom or molecule which has acquired electrical charge by either losing electrons (resulting in a positively charged ion) or gaining electrons (resulting in a negatively charged ion).

Iris: Colored portion of the eye.

Irrigation: The transport of water through ditches or pipes to fields to water crops.

J

Joint: A place in the body where bones meet.

K

Keratinocytes: Skin cells that make a protein called keratin, which protects the skin.

L

Lactic acid: A carboxylic acid formed during the metabolism of sugar in muscle cells. A buildup of lactic acid leads to a feeling of fatigue.

***Lactobacillus*:** Bacteria that create lactic acid.

Lamarckism: The belief that acquired characteristics can be inherited, that is, that changes to an organism that happen during its life can be passed on to offspring.

Landfill: An area of land that is used to dispose of solid waste and garbage.

Leaching: The movement of dissolved chemicals with water percolating through soil.

Leaven: Yeast, baking soda, or baking powder that causes bread to rise by producing carbon dioxide gas.

Leukemia: A cancer of the blood-producing cells in bone marrow.

Ligaments: Structures that hold the bones of joints in the proper position.

Lipid: A family of compounds that are oily, fatty, or waxy, and cannot dissolve in water.

Liposome: A sphere composed of lipid, or fats.

Lymphocyte: A cell that functions as part of the lymphatic and immune systems by attacking specific invading substances.

Lymphoma: A cancer of the blood cells that are part of the active immune system.

Lysenkoism: A type of pseudoscience that arose in the Soviet Union in the 1930s and destroyed Soviet biology for decades. Lysenkoists denounced modern evolutionary biology and genetics.

M

Magnetic resonance imaging (MRI) scanners: A machine that uses magnetic fields and computer interpretation to produce images of the body's tissues.

Magnetism: The force that attracts or repels various substance, especially metals, which is due to the motion of electric charges.

Maize: Another word for corn, a cereal grain.

Menopause: The time in a woman's life when the chemical environment of her body changes, resulting in the cessation (stopping) of her menstrual period.

Metabolic: Related to the chemical processes of an organ or organism.

Metabolism: Chemical changes in body tissue that convert nutrients into energy for use by all vital bodily functions.

Metabolize: Any cellular chemical activity that converts nutrients to energy.

Metal: A shiny elemental chemical substance that is a good conductor of heat and electricity, and when polished, a good reflector of light.

Metastasize: The spread of cancer from one part of the body to another.

Methane: A gas resulting from the anaerobic digestion of organic matter by bacteria.

Methanol: An alcohol, used as an antifreeze, fuel, or solvent.

Microarray: A regular grid of spots containing biological molecules or living cells on the surface of a biochip.

Microbe: A microorganism or germ.

Microorganism: A tiny organism, too small to be seen without a microscope, such as a virus or bacterium.

Milling: Chewing and pulverizing hard seed into a powdery texture.

Mineral: A naturally occurring solid substance of nonbiological origin, having definite chemical composition and crystal structure.

Mitochondria: An organelle that specializes in ATP formation, the "powerhouse" of the cell.

Molecule: A chemical combination of atoms, and the smallest amount of a chemical substance.

Monoclonal antibodies: Antibodies produced from a single cell line that are used in medical testing and, increasingly, in the treatment of some cancers.

Monomer: A substance composed of molecules that are capable of joining together to form a polymer.

Mutation: A change in a gene's DNA that is not present in the parents' DNA. Whether a mutation is harmful is determined by the effect on the product for which the gene codes.

N

Nanometer: The distance equal to one-billionth of a meter.

Narcotic: A drug that depresses the central nervous system and is usually addictive.

Nectar: The sweet liquid that flowering plants make to attract insects and small birds, which help to pollinate those plants.

Neuron: A nerve cell. Neurons may be either sensory (involving the senses) or motor (involved in motion).

Neurotransmitters: Biochemical substances that transmit nerve impulses between nerve cells.

Nuclear transfer: Transfer of the central portion of living cells (those that contain a nucleus) that contains the genetic material. Technique used in cloning.

Nucleotide: Molecular unit that is the building block of DNA.

Nucleus: A compartment in the cell which is enclosed by a membrane and which contains cellular genetic information.

Nutrient: A substance that provides nourishment.

O

Oil: Animal or vegetable fat that is liquid at room temperature.

Oleochemicals: Chemicals derived from vegetable oils.

Opium: A natural product of the opium poppy, *Papaver somniferum*. Cutting the immature pods of the plant allows milky liquid to seep out and be collected. Air-dried, this is crude opium.

Organ Procurement and Transplantation Network (OPTN): A program that promotes organ donation and oversees the national distribution of organ transplants.

Organic farming: Farming that uses no artificial chemicals or genetically engineered plants or animals.

Organic materials: Any biomass of plants or animals, living or dead. The most important form of organic matter in soil is dead or decaying.

Organic: A term used to describe molecules containing carbon atoms.

Organism: Any living thing.

Ovaries: Female reproductive organs that contain unfertilized eggs.

Oxidation: A biochemical process which is part of metabolism. It involves the steady but relatively slow release of energy from food molecules for cell activity.

Ozone: A gas made up of three atoms of oxygen. Pale blue in color, it is a pollutant in the lower atmosphere, but essential for the survival of life on Earth's surface when found in the upper atmosphere because it blocks dangerous ultraviolet solar radiation.

P

Parallelism: The performance by a computer of two or more calculations at the same time.

Parkinson's disease: Disease of the nerves that causes the patient to gradually lose control of their muscles. Loss of a chemical in the brain called dopamine causes shaking and muscle stiffness.

Pasteurization: A method for treating milk and other liquids by heating them to a high enough temperature for a long enough period of time to kill or inactivate any microorganisms present in the liquid.

Patent: A grant given by a governmental body that allows a person or company sole rights to make, use or sell a new invention.

Paternity testing: Genetic testing to determine the father of an offspring.

Paternity: The genetic father of an offspring.

Pathogen: A disease-causing agent, such as a bacteria, virus, fungus, etc.

PCR: Polymerase chain reaction. A method of making many copies of a short piece of DNA quickly in a laboratory.

Penicillin: First antibiotic discovered (1928). Initially obtained from mold extracts.

Peritoneal dialysis: An alternative to hemodialysis in cases of kidney failure. Instead of pumping blood out of the body, dialysis fluid is drained into and out of the abdomen to absorb toxins.

Pesticide: A chemical meant to kill plants or insects that hurt crops.

pH: A measurement of the concentration of hydrogen ions in a solution of water. A neutral solution with equivalent amounts of hydrogen and hydroxyl ions has a pH of 7.0 at room temperature. Acidic solutions have a pH of less than 7.0 and basic (alkaline) solutions have a pH of more than 7.0.

Pharmaceutical: A drug, medicine, or vaccine.

Pharmacogenetics: The study of how a person's genetic makeup affects his or her response to medications.

Pharmacogenomics: The study of how human genetic variations affect responses to medications.

Pharmacology: The science of the properties, uses, and effects of drugs.

Phenylketonuria: A genetic disorder in which human body fails to produce the enzyme that breaks down phenyalanine. Accumulation of phenylalanine causes brain damage.

Pheromone: Smell-producing chemical that provides communication between animals.

Phospholipids: A molecule consisting of a phosphate head and two fatty acid chains that dangle from the head; the component of the plasma membrane.

Photosynthesis: Biological conversion of light energy into chemical energy by plants.

Physiologist: A person who studies living plants.

Pituitary gland: In humans, a structure (organ) below the brain that releases human growth hormone.

Plant propagation: The process of spreading plants either artificially or naturally.

Plasma: The liquid part of the blood. Contains clotting elements.

Plasmid: A circular piece of DNA that exists outside of the bacterial chromosome and copies itself independently. Scientists often use bacterial plasmids in genetic engineering to carry genes into other organisms.

Plasticizer: Substances added to plastics to make them flexible. For example, polystyrene by itself is hard and brittle.

Plastics: A group of natural or synthetic polymers that are capable of being softened and molded by heat and pressure; also sometimes used to include other structural materials, films, and fibers.

Platelets: Irregularly shaped disks found in the blood of mammals that aid in clotting the blood.

Pluripotent: Pertaining to a cell that has the capacity to develop into any of the various tissues and organs of the body.

Polio: A disease (poliomyelitis) caused by a virus that can result in muscle weakness, paralysis, or death.

Pollen: Cells of a plant that contain male DNA.

Pollination: Movement of pollen from the male reproductive organ to the female reproductive organ, usually followed by fertilization.

Pollution: An undesired substance that contaminates another system (air, ground, water, etc.).

Polychlorinated biphenyls (PCBs): A compound of biphenyl and chlorine that is considered a hazardous pollutant.

Polymer: A chemical compound formed by the combination of many smaller units.

Polymerase chain reaction (PCR): A method of making many copies of a short piece of DNA quickly in a laboratory.

Polymerizing: The process by which smaller chemical units are linked into a chain to form a polymer.

Polysaccharide: A molecule composed of many glucose subunits arranged in a chain.

Polystyrene: A type of rigid plastic used for making CD jewel cases, disposable cutlery, and other plastic objects that need to be stiff.

Polyunsaturated fat: A fat missing two or more hydrogen atoms from the maximum number that can be bonded to carbon atoms of a compound. These fats can remain liquid at room temperatures.

Predator: An insect or animal that kills and eats other insects or animals.

Preservative: A compound added to food products to ensure they do not spoil.

Primary graft dysfunction: A severe lung injury that occurs in some lung transplant patients.

Primer: In the polymerase chain reaction used to copy DNA, primers are short lengths of DNA that attach to the single-stranded DNA template and tell DNA polymerase where to start copying and where to stop.

Progesterone: Hormone secreted by the female reproductive organs; used in birth control.

Promoter: A gene that makes the cell produce the protein described by a second gene.

Prostaglandin: A fatty acid in the stomach that protects it from ulcerating.

Prosthetic: An artificial replacement for a lost limb or other body part. An artificial leg is a prosthesis, as is a replacement heart valve.

Protein: Complex molecules that cells use to form most of the structures and control chemical reactions within a cell.

Pseudoscience: Any system of beliefs that claims to be scientific but does not follow the scientific method by which scientific knowledge is produced.

Purify: To make something clean by getting rid of any impurities.

R

Radar: A method of detecting distant objects based on the reflection of radio waves from their surfaces.

Radiation: Energy in the form of waves, or particles.

Radioactive: The production of high-energy rays as a result of changes in the atomic structure of matter.

Reagent: A chemical added to a suspect material to produce a known reaction response. If the reaction response is observed as expected, the identity of the material is assumed to be known.

Recombinant bovine growth hormone: Bovine growth hormone made using genetically engineered (recombinant) bacteria. Called rbGH for short. Given to cows to increase milk production.

Recombinant DNA: DNA that is cut using specific enzymes so that a gene or DNA sequence can be inserted.

Recombinant DNA technology: A technique for cutting and splicing together DNA from different sources.

Recombinant proteins: Proteins that are produced when DNA from two different organisms is combined.

Red blood cells: Hemoglobin-containing blood cell that transports oxygen from the lungs to tissues. In the tissues, the red blood cells exchange their oxygen for carbon dioxide, which is brought back to the lungs to be exhaled.

Regeneration: The ability of an organism to reproduce a part of itself completely.

Rejection: An event that occurs when the body's defense (immune) system attacks a transplanted organ.

Rennet: An enzyme extracted from animal stomachs, used to curdle milk while making cheese.

Reproductive cells: Specialized cells capable uniting in the sexual cycle; female gametes are termed egg cells; male gametes may be zoospores or sperm cells.

Resistance: An immunity developed within a species (especially bacteria) via evolution to an antiobiotic or other drug.

Restriction enzyme: A special type of protein that can recognize and cut DNA at certain sequences of bases to help scientists separate out a specific gene.

Restriction length fragment polymorphism (RFLP): A variation in the DNA sequence, identifiable by restriction enzymes.

Retina: An extremely light-sensitive layer of cells at the back part of the eyeball. Images formed by the lens on the retina are carried to the brain by the optic nerve.

Retrovirus: A virus whose genetic material is RNA (ribonucleic acid), not DNA.

RNA: Ribonucleic acid. Used by most cells to copy protein recipes from DNA; in retroviruses, RNA is the primary genetic material.

S

Salinity: The amount of dissolved salts in water.

Sanitization: Cleaning or disinfecting to remove living material, like germs.

Saponifiation: A chemical reaction involving the breakdown of triglycerides to component fatty acids, and the conversion of these acids to soap.

Saturated fat: A fat containing the maximum number of hydrogen atoms that can be bonded to carbon atoms in the compound.

Scanning tunneling microscope: A device that emits a focused beam of electrons to scan the surface of a sample. Secondary electrons released from the sample are used to produce a signal that can, in turn, produce an image.

Scion: The upper or transferred component of a grafted plant.

Sediment: Soil and rock particles that wash off land surfaces and flow with water and gravity toward the sea. On the sea floor, sediment can build up into thick layers. When it compresses under its own weight, sedimentary rock is formed.

Septic tank: An underground tank, usually outside of a home, in which bacteria are used to break down and treat wastewater.

Sequencing: Finding the order of chemical bases in a section of DNA.

Silicone: A controversial substance that has been used in breast and other types of implants. It is classified as a high-risk category material by the FDA.

Single nucleotide polymorphisms (SNPs): Changes to a single nucleotide (A, C, T, or G) in a DNA sequence.

Skin: The largest organ of the body that provides a protective covering for internal structures and helps regulate body temperature.

Smallpox: A deadly viral disease that was eradicated in the 1970s. Today the virus only exists in closely-guarded samples held by the American and Russian governments.

Solvent: A substance (usually liquid) that can dissolve another substance.

Somatic cell gene therapy: The introduction of genes into tissue or cells to treat a genetic related disease in an individual.

Somatic cell: Cells that are part of the body but are not in the germline (able to pass their DNA on to future generations). Any type of cell in the body that is not a sperm or egg cell.

Sonar: SOund Navigation And Ranging. A device utilizing sound waves to determine the range and direction to an underwater object.

Spore-like stem cell: An unspecified cell that remains in a dormant state in the body until they are stimulated to divide and form specialized cells.

Stanol ester: A group of chemical compounds that reduce the amount of low-density lipoprotein (LDL) cholesterol in blood.

Stem cell: An unspecialized cell that can divide to form other types of specialized cells in the body. Stem cells give rise to cells that have specialized form and function such as nerve or muscle cells.

Sterilization: An operation that makes a person unable to have children. Usually this is done by cutting or tying off the tubes that convey eggs or sperm to the sexual organs.

Steroid: A group of organic compounds that belong to the lipid family and that include many important biochemical compounds including the sex hormones, certain vitamins, and cholesterol.

Stimuli: An agent, action, or condition that elicits a response.

Stock: The lower part of a graft, which generally turns into the root system of the resulting plant (also called a rootstock or understock).

Stoichiometry: Deals with determining proportions of elements and compounds in chemical reactions.

Stroke: Blockage of an artery bringing blood to part of the brain. May injure or kill part or all of the brain.

Styrofoam: The brand name for specially treated polystyrene. Commonly used to manufacture packing peanuts and food packaging material.

Substrate: The foundation material on which integrated circuits are built; usually made of silicon.

Surrogate: A female who carries another animal's genetic offspring.

Sustainable agriculture: Agricultural use that meets the needs and aspirations of the present generation, without compromising those of future ones.

Synthetic: Referring to a substance that either reproduces a natural product or that is a unique material not found in nature, and which is produced by means of chemical reactions.

T

Tachycardia: An elevated heart rate due to exercise or some condition such as an anxiety attack.

Technology agreement: A contract signed by a farmer in order to buy seed from a genetic engineering company. The farmer agrees to not use seed harvested from the genetically engineered crop.

Tendons: Strong pieces of tissue that connect muscles to bones.

Terminal: Causing, ending in, or approaching death; fatal.

Thermal cycler: A machine used to precisely heat and cool the mixture used in the PCR (polymerase chain reaction).

Thorax: The area just below the head and neck; the chest.

Three-dimensional: A visual representation in terms of height, width, and depth, as opposed to a "flat" image that represents only height and width.

Tissue engineering: Artificial products that are made from natural biological materials.

Tissue: Groups of cells with a similar function.

Toxic: Something that is poisonous and that can cause illness or death.

Toxin: A poison that is produced by a living organism.

Transfusion: A technique used to replace blood lost during an accident, illness, or surgery.

Transgene: A gene from one organism that is inserted into the genome of another organism.

Transgenic plant: A plant that has successfully incorporated a transferred gene or constructed piece of DNA into its genome.

Transgenic: A genetically engineered animal or plant that contains genes from another species.

Transplantation: Moving cells or tissues from their point of origin in one organism to a secondary site in the same or a different organism.

Triclocarban: A chemical that kills bacteria.

Triclosan: A chemical that kills bacteria. Most antibacterial soaps use this chemical.

Triglyceride: Natural fat in tissue, which comes from animal and plant fats and oils, that is considered dangerous to human health.

Tumor: An uncontrolled growth of tissue, either benign (noncancerous) or malignant (cancerous).

Turbine: A device consisting of a series of baffles mounted on a wheel around a central shaft used to convert the energy of a moving fluid into the energy of mechanical rotation.

Turing machine: Imaginary general-purpose computer that reads instructions from one infinite tape and writes output symbols on another. Named after its inventor, British mathematician Alan Turing (1912–1954).

U

Udder: The milk-secreting organ of a cow, sheep, or goat.

Ultrasound imaging: Computer-generated images of ultrasonic waves passed into the body.

United Network for Organ Sharing (UNOS): A Richmond, Virginia company that runs the Organ Procurement and Transplantation Network.

Unsaturated fat: Fats found in vegetable oils including canola, peanut, olive, sunflower, safflower, soybean, corn, and cottonseed. Unsaturated fats are healthier than saturated fats.

Uterus: Organ in female mammals in which the embryo and fetus grow to maturity.

V

Vaccine: A product that produces immunity by inducing the body to form antibodies against a particular agent. Usually made from dead or weakened bacteria or viruses. Vaccines cause an immune system response that makes the person immune to (safe from) a certain disease.

Vascular constriction: The muscular contraction or narrowing of blood vessels in response to injury.

Vector: A vehicle that delivers foreign genes to another organism's DNA.

Virus: A very simple microorganism, much smaller than bacteria, that enters and multiplies within cells. Viruses often exchange or transfer their genetic material (DNA or RNA) to cells and can cause diseases such as chickenpox, hepatitis, measles, and mumps.

Vitamin A: A substance found in food (or made by the body from substances found in food) that is needed for metabolism (a body's chemical reactions). Lack of vitamin A can cause blindness.

Vitamin E: Substance that occurs naturally in human beings and is responsible for maintaining youthful skin.

W

Whey: The liquid part of milk that is separated from the curd when making cheese and other products that curdle milk.

White blood cells: Leukocytes. Cells that help fight infection and disease.

Whooping cough: An acute infectious disease caused by *Bordetella pertussis* that causes spasms of coughing and convulsions.

Woad: A blue dye obtained from the woad plant.

Wort: The sugar-water solution made when malted barley is steeped in water and its complex sugars break down into simple sugars.

X

X ray: Electromagnetic radiation of very short wavelength, and very high energy. Used for medical imaging.

Xenograft: Tissues and organs used for transplantation that come from different animal species, like pigs or baboons.

Xenotransplantation: Transplantation of tissue or an organ from one species to another, for example from pig to human.

Y

Yeast: A microorganism of the fungus family that promotes alcoholic fermentation, and is also used as a leavening (agent that makes dough rise) in baking.

Z

Zygote: The cell resulting from the union of the male sperm and the female egg. Normally the zygote has double the chromosome number of either the sperm or egg, and gives rise to a new embryo.

Antibiotics, Biosynthesized

Description

Antibiotics are drugs that kill bacteria living inside an animal without harming the animal.

Bacteria are single-celled life forms that can be either helpful or harmful. The human body needs many billions of the bacteria called *Escherichia coli* in the intestines to be healthy, but other bacteria, such as *Streptococci pyogenes*, can cause sickness or even death. *Streptococci pyogenes* causes strep throat; other bacteria can cause other diseases.

The word “antibiotic” is often reserved for a drug that kills bacteria. A drug that kills viruses (which are smaller and simpler than bacteria) is called an antiviral, and a drug that kills parasites inside the body is an antiparasitic. Substances that kill bacteria and viruses outside the body, but that would be poisonous inside the body, are called disinfectants, antimicrobials, or antibacterials. For example, ordinary household bleach (sodium hypochlorite) is a disinfectant, but it is not an antibiotic because it cannot be used to kill bacteria inside the body. Bleach is poisonous to people as well as to bacteria.

Most antibiotics are produced by special bacteria or fungi. These bacteria or fungi are grown in large cultures; the substances they produce are then harvested and purified for medical use. Antibiotics produced in this way are called biosynthesized antibiotics. *Bio* means “life” and *synthesize* means “to make,” so biosynthesized means made by living things. There are also synthetic antibiotics, which are chemicals made in factories without the help of living things. Most antibiotics are still biosynthesized.

Antibiotics can be either swallowed in pill form or injected directly into the bloodstream using a needle. Direct injection is used only for more serious infections.

Scientific Foundations

Antibiotics kill bacteria without harming other cells by attaching themselves to complex molecules called enzymes. Enzymes, which are found inside bacteria as well as on their outer shell, help chemical reactions to happen in the bacterial cell. Each enzyme participates in a different chemical reaction. By attaching to an enzyme, an antibiotic can stop the enzyme from doing its job. Depending on which enzyme is targeted, the bacterial cell can be affected in several different ways. Its outer shell (cell wall) may break up, for example, or it may be unable to reproduce.

Enzymes can be different in different cells, such as bacteria and body cells, and still do the same job. Antibiotics interfere only with the kinds of enzymes that bacteria use.

Development

In the 1920s, a Scottish biologist named Sir Alexander Fleming (1881–1955) discovered that tears and sweat contain a substance he called lysozyme. Lysozyme slows bacterial growth, but is not strong enough to work as an antibiotic. In 1928, however, Fleming accidentally discovered that a kind of mold called *Penicillium*—which can grow on old bread—produces a substance that kills bacteria. Fleming left some dishes intended to grow bacteria sitting around his laboratory so long that they got moldy. As he was cleaning the dishes he noticed that the mold had killed the bacteria near it on the dish. He isolated the substance that killed the bacteria and called it penicillin, after the type of mold that made it. Penicillin was the first true antibiotic. Since it is made by a mold, it is one of the biosynthesized antibiotics.

It was not until 1940 that researchers at Oxford University in England discovered how to produce enough penicillin for it to be practical as a medicine. During World War II (1939–45), penicillin saved many soldiers' lives by fighting infections in wounds.

Current Issues

Scientists are always looking for new antibiotics because bacteria become resistant or immune to the old ones. Bacteria become resistant because they evolve. Not all bacteria are exactly alike; some of them make slightly different enzymes than others of their kind. In any large group of a certain kind of bacteria, a few individuals are likely, by chance, to have enzymes that are so different that a given antibiotic does not kill them. If the whole population is attacked with an antibiotic, these different, resistant

New, Improved—and Dangerous?

Today, most household hand soaps are labeled ‘‘antimicrobial.’’ This means that they contain a substance that kills bacteria. Some scientists worry that subjecting the bacteria in all the kitchens and bathrooms of the country to these antimicrobial chemicals will force them to evolve resistance. ‘‘We are creating an environment of bacteria that are resistant to these products,’’ says Dr. Stuart Levy, a researcher at Tufts University, ‘‘and they may well be resistant to antibiotics as well . . . . [T]here is an unfortunate mounting rage for antibacterial chemicals added to normal cleansings. And I think that this will create a changed microbiology and very likely, at least in the laboratory, contribute to the propagation of resistant bacteria.’’ Yet other researchers say that there is no sign of such resistance developing because of antimicrobial soaps.

bacteria will survive. The next generation of bacteria will resemble the survivors, so when the population grows again, the same antibiotic will not work.

In the real world, bacterial resistance does not evolve quite so simply. Nevertheless, it does evolve over time, and it is a serious medical problem. A resistant strain of bacteria is often resistant to only one or two antibiotics, and can be treated simply by switching to a different antibiotic. However, a person can be infected by a type of bacteria that has evolved resistance to all known antibiotics. Some strains of the most dangerous bacteria, such as the bacterium that causes tuberculosis, have already evolved resistance to all known antibiotics. Resistant tuberculosis bacteria first appeared in the 1980s. The World Health Organization (WHO, the United Nations agency for health) declared in 1992 that resistant tuberculosis was a world health emergency.

Resistance is also the reason why some scientists question the use of antibiotics in raising animals for food. Antibiotics are fed to cows, chickens, turkeys, and pigs in order to make them grow faster by killing off most of the bacteria in their bodies. About fifty million pounds of antibiotics are produced in the United States every year, and about sixteen million pounds are fed to livestock to make them grow faster. However, many scientists think that dumping so many antibiotics into the environment may be helping antibiotic-resistant strains of bacteria to become more common.

Scientists are constantly looking for new antibiotics to stay one jump ahead of the ever-evolving, disease-causing bacteria of the world. One method of producing new antibiotics is to try to

Words to Know

Antibiotics: Drugs that target and kill bacteria, but are ineffective against viruses.

Antimicrobial: A material that slows the growth of bacteria or that is able to to kill bacteria. Includes antibiotics (which can be used inside the body) and disinfectants (which can only be used outside the body).

Biosynthesis: Production of a chemical compound by a living organism, as in metabolism.

Enzyme: A protein that helps control the rate or speed of chemical reactions in the cell.

Penicillin: First antibiotic discovered (1928). Initially obtained from mold extracts.

Resistance: An immunity developed within a species (especially bacteria) via evolution to an antiobiotic or other drug.

genetically engineer antibiotic-making bacteria—to actually change the bacteria's genes to force them to make new antibiotics. The goal is to create new antibiotics faster than bacteria can evolve resistance to them.

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[*See Also* **Vol. 3, Antimicrobial Soaps; Vol. 2, Genetic Engineering; Vol. 1, Penicillins.**]

Anti-Rejection Drugs

Description

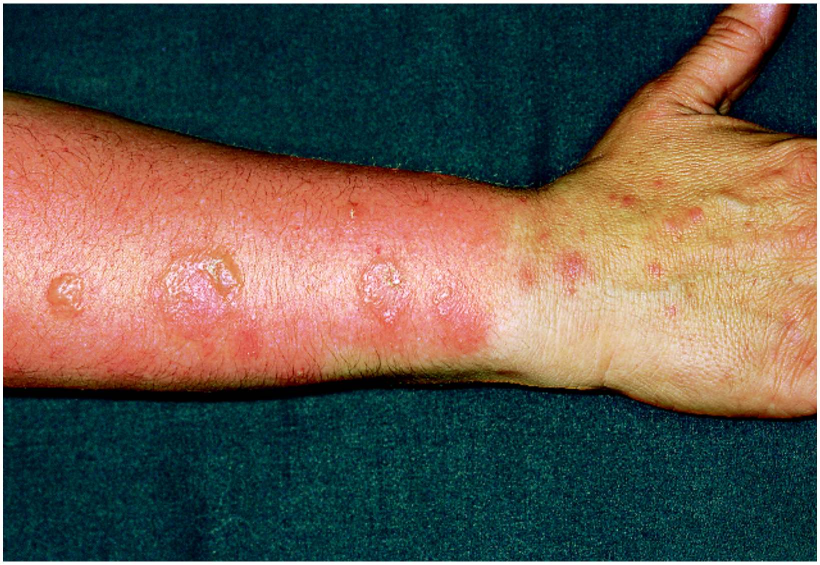
Anti-rejection drugs, called immunosuppressants, are used to prevent rejection in someone who has had an organ transplant. This is when doctors take an organ from a donor's body and implant it into a recipient's body, where it replaces a failing organ. Anti-rejection drugs help block the immune system to keep it from rejecting the transplanted organ, but still allow the person's immune system to fight off diseases.

Doctors have known for many years how to transplant organs. The remaining challenge is the immune system, which protects the body by fighting off bacteria and other substances that it sees as foreign. When the immune system detects something as foreign, it sends white blood cells called T-lymphocytes to attack it. The immune system usually considers a transplanted organ as foreign and tries to destroy it. This is called rejection. A person who rejects his or her new organ can become very sick and can even die.

When people start taking anti-rejection drugs, they take them in very high doses. After a few months, the risk of rejection goes down as the body gets used to the new organ. The patient can then take lower doses of the anti-rejection drugs.

Scientific Foundations

Anti-rejection drugs work by blocking the immune response from attacking the new organ. Some anti-rejection drugs limit the number of T-lymphocyte cells, so there are fewer of them to attack the organ. Others slow the production of substances in the body that are used to make T-lymphocyte cells. Steroid drugs such as prednisone reduce the swelling that occurs with an immune response.



This person's arm shows drug-induced photosensitivity from taking cyclosporine. Photosensitivity means that a person is more sensitive to sunlight, and being in the sun caused the redness and blisters on the arm. *Dr. P. Marazzi/Photo Researchers, Inc.*

The most common anti-rejection drugs are:

- Cyclosporine—This drug comes from a fungus. It stops the activation of T-lymphocytes to prevent them from attacking the organ. Patients take it once or twice a day. Its side effects include high blood pressure, shaking, kidney or liver damage, and tender gums.
- Prednisone—This drug is a steroid. The body naturally makes steroids. Steroids reduce the swelling that occurs with an immune response. This drug is often used with cyclosporine.
- Tacrolimus—This drug works like cyclosporine. It prevents immune cells from causing rejection. Its side effects include high blood pressure, shaking, headache, and nausea.
- Sirolimus—This drug blocks the action of T-lymphocytes to prevent them from attacking the organ. It is usually combined with prednisone and cyclosporine. Its side effects include upset stomach, infection, shaking, and some kinds of cancer.
- Azathioprine (brand name Imuran)—This drug blocks production of white blood cells that cause rejection. Its side effects include nausea, rash, muscle pain, and infection.
- Mycophenolate mofetil (brand name CellCept)—This drug also holds back the immune system so that it does not reject the new organ. Its side effects include loose stools (diarrhea), lower numbers of white blood cells, blood infection, and other kinds of infections.

Souvenir Soils

Several pharmaceutical companies encourage their employees to collect and bring back soil samples during their vacation travels. Anti-rejection drugs such as drugs cyclosporine and tacrolimus are made from fungi found in soils in different parts of the world.

Development

Doctors have been able to transplant an organ from one person to another since the early 1900s. But in those days, every time they transplanted an organ, the person who received it would reject the organ and eventually die.

In the 1950s, doctors performed the first successful kidney transplant. The patients were identical twins. Because their tissue matched so closely, the risk for rejection was lower.

Once doctors understood the immune response that caused a patient's body to reject the new organ, they tried to use high-energy rays (radiation) all over the patient's body to reduce the rejection. However, radiation is toxic and did not prevent rejection of the transplanted organ.

In the early 1960s, Roy Calne of Peter Bent Brigham Hospital (now Brigham and Women's Hospital) in Boston, Massachusetts, studied drugs that blocked the immune response to prevent rejection. He experimented with a drug called azathioprine. Azathioprine worked well to prevent rejection, especially when combined with prednisone, a steroid drug.

The turning point for organ transplants came in 1983, when the U.S. Food & Drug Administration (FDA) approved cyclosporine as an anti-rejection drug. A Swiss biochemist named Jean-François Borel discovered the drug cyclosporine in 1972. He made this drug from a fungus. Cyclosporine blocked the actions of T-lymphocyte immune cells. It helped stop the immune system from rejecting transplanted organs and improved the survival rate after organ transplants. Doctors found that cyclosporine worked best with prednisone or azathioprine. This allowed more people to have successful organ transplants.

In the 1990s, the FDA approved three new anti-rejection drugs: tacrolimus, sirolimus, and mycophenolate mofetil. These drugs improved transplant survival rates even more.

Words to Know

Bacteria: Microscopic organisms whose activities range from the development of disease to fermentation.

Biochemist: A scientist who studies biochemistry (the study of the molecules and chemical reactions in living things).

Immunosuppressants: Drugs or radiation used to reduce the immune system's ability to function.

Radiation: Energy in the form of waves, or particles.

Rejection: An event that occurs when the body's defense (immune) system attacks a transplanted organ.

Steroid: A group of organic compounds that belong to the lipid family and that include many important biochemical compounds including the sex hormones, certain vitamins, and cholesterol.

Most transplant patients take anti-rejection drugs once or twice a day. Each drug works in a different way and has different side effects. Sometimes people take more than one drug at a time.

Current Issues

Researchers are evaluating several new anti-rejection drugs that are anticipated to work as well as the existing drugs, but with fewer side effects. One of these new drugs is called belatacept. In research studies, belatacept worked as well on kidney transplant patients as cyclosporine.

Other new anti-rejection drugs that are being studied trick the patient's body into not rejecting the new organ. One treatment method involves putting small pieces of tissue from the donor into the patient's body before the organ is transplanted.

Taking anti-rejection drugs in different ways may help them work better. In January 2006, scientists studied lung transplant patients who breathed in (inhaled) cyclosporine instead of swallowing it. The study found that people who inhaled cyclosporine were less likely to reject their new organ than people who took the drug by mouth.

Scientists are also looking at ways to prevent rejection with fewer or no drugs. In the 1990s, doctors discovered that some people could slowly stop taking anti-rejection drugs and still not reject their organ. This is because their immune system eventually accommodates the new organ. Scientists are trying to figure out the best way to safely have people stop taking their anti-rejection drugs.

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[*See Also* **Vol. 1, Organ Transplants.**]

Arthritis Drugs

Description

Arthritis is the name given to a group of diseases in which the joints located between adjacent bones become stiff and sore. The stiffness and soreness is partially due to a process called inflammation—swelling of tissue that occurs when the body's immune system reacts against a molecule. (The immune system is designed to recognize and attack foreign substances in the body.) The joint pain, swelling, and stiffness of arthritis can make daily life hard. Over time, as inflammation continues, the joint can become less and less capable of movement. One example is the increasing stiffness of fingers that can occur in some people. Even simple tasks like holding a knife and fork can become difficult.

As of 2006 there was no cure for arthritis. However, some drug treatments can lessen the discomfort or slow the progress of some forms of the disease.

Scientific Foundations

Arthritis drugs work in different ways. Some drugs target a molecule of the immune system called a cytokine that directly triggers inflammation. These drugs are designed to attach to the molecule. This stops the molecule from stimulating inflammation.

Other drugs are more indirect in their activity. Instead of binding directly to the target molecule (one that causes inflammation), they stop the target from binding (attaching) to sites on other cells in the body. These binding sites are called receptors. Binding of a target molecule to the receptor can send a signal that starts other reactions that can lead to arthritis. By preventing the binding to the receptor, the signal is prevented from forming, and so the arthritis process is blocked.

False-color x ray of hands deformed by severe arthritis. *© CNRI/Photo Researchers, Inc.*

The receptor strategy is a race between the arthritis drug and the target molecule for the receptor site. If there are more drug molecules present, they will be more likely to bind to the receptor and block the binding of the target molecule.

One type of arthritis that has benefited from the use of arthritis drugs is rheumatoid arthritis. This form of arthritis occurs when the body's immune system somehow recognizes components of the body as being foreign, and so attempts to dispose of the invader. The body attacks itself. Over time, this increasingly destroys joints.

Development

Monoclonal antibodies are drugs that have been developed to combat arthritis.

The basis of the monoclonal antibody approach is the antibody. An antibody is a protein produced by a cell called a lymphocyte in

Cytokines and Obesity

The central role played by cytokines in the regulation and function of the immune system may have benefits other than the treatment of arthritis. A cytokine called interleukin-7, which is critical in the maintenance of immune cells, can also prevent obesity in a genetically engineered mouse (where a gene has been altered or replaced) that has a hypothalamus—a part of the brain associated with appetite—that does not work properly. Normally, the mice overeat and gain weight. However, injections of the cytokine produce mice of normal weight. Scientists think that the cytokine binds to the hypothalamus, somehow correcting the appetite-associated defect. Someday, weight-loss plans may include cytokine supplementation.

response to a foreign protein (an antigen). A certain type of lymphocyte produces a certain type of antibody. Since there can be many versions of lymphocytes, a huge variety of antibodies can be generated.

Lymphocytes do not stay alive indefinitely when grown outside the body, making it difficult to produce a lot of antibody for drugs. The discovery of monoclonal antibodies has made it possible to produce specific antibodies in large amounts.

Monoclonal antibodies were developed in 1974 by César Milstein (1927–2002) and Georges Köhler (1946–1995). The scientists discovered that antibody-producing cells called lymphocytes could be combined with cells obtained from tumors. Tumor cells are characterized by their ability to grow indefinitely. The resulting fusion between the lymphocytes and tumor cells produced cells that continuously made a particular type of antibody. By using different lymphocytes, Milstein and Köhler generated many types of antibody-producing cells that lived almost indefinitely. For this discovery the scientists shared part of the 1984 Nobel Prize in Physiology or Medicine.

Monoclonal antibodies to cytokine and various receptors important in arthritis have been developed and tested. Because the basis of the strategy is the recombination of two types of cells (the lymphocytes and the tumor cells), it is referred to as recombination therapy. The results have been encouraging. Assessment of the drugs in animals that develop conditions similar to human arthritis, and in clinical trials that actually test the drug in humans have indicated that the drugs are beneficial and, at least so far, acceptably safe. (There is always a risk from drug therapy, but if the risk is very small and the side effects are not too dangerous, then the use of the drug can be permitted.)

Words to Know

Antibody: A molecule created by the immune system in response to the presence of an antigen (a foreign substance or particle). It marks foreign microorganisms in the body for destruction by other immune cells.

Antigen: A molecule, usually a protein, that the body identifies as foreign and toward which it directs an immune response.

Arthritis: Inflammation of the joints.

Cytokine: Molecules produced by cells to control reactions between other cells.

Immune system: A system in the human body that fights off foreign substances, cells, and tissues in an effort to protect a person from disease.

Lymphocyte: A cell that functions as part of the lymphatic and immune systems by attacking specific invading substances.

Monoclonal antibody: Antibodies produced from a single cell line that are used in medical testing and, increasingly, in the treatment of some cancers.

Current Issues

Despite the optimism of the clinical trial data, issues need to be resolved before such recombinant therapy is routinely used in the treatment of arthritis.

One current issue concerns the long term effects of treatment. Whether the treatments prevent joint damage over time is less clear, for example. This is expected, but still needs to be shown. Also, it must be shown that the treatment itself does not cause any damage when used for a long time.

Another current issue is the potential benefit of the deliberate introduction of receptors into a patient. The reasoning here is that receptors that are floating in solution will bind the cytokine before it can bind to a surface-bound receptor and trigger the problematic immune responses. Much research is still needed to show that this strategy is effective and safe.

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[*See Also* **Vol. 1, Corticosteroids.**]

Aspirin

Description

Aspirin is a drug used to treat pain and fever. It is called an anti-inflammatory drug because it also helps reduce swelling (inflammation) following injury.

Aspirin has been sold for more than one hundred years. It is used more than any other pain reliever in the world and is one of the least expensive treatments for arthritis (a disease of the joints usually found in older adults that can make movement painful). Aspirin is also the main ingredient in many combination drugs. According to aspirin makers, Americans take more than eighty billion tablets of aspirin a year.

In addition to being a painkiller, aspirin is a potential life saver. In recent years, scientists have shown that some people who take aspirin during a heart attack have a better chance of surviving. Aspirin is the only over-the-counter painkiller approved for the prevention of some types of heart disease and stroke (the blockage or rupture of a blood vessel in the brain) when taken regularly in small amounts. It is important to talk with a physician before using aspirin to prevent a heart attack or stroke because aspirin can increase chances of internal bleeding (the leaking of blood from blood vessels into spaces in the body) if not used properly.

Scientific Foundations

How aspirin actually worked remained a mystery for a long time. In the 1980s, British scientist John R. Vane (1927–2004) showed how aspirin stops the body from making a chemical called prostaglandin. Prostaglandin, among other functions, can cause tight muscles and contract blood vessels. This sometimes leads to pain and swelling. Prostaglandins are found in swollen tissues and

TABLETTEN „BAYER" zu
BAYER
ASPIRIN
Name gesetzl. geschützt
lässt 1-2 Tabletten in etwas
fallen und trinkt sogleich nach
Einnehmen reichlich Wasser
Farbenfabriken
FRIEDR. BAYER & Co. Leverkusen

A bottle of Bayer aspirin from around 1912, when it became the first mass-produced medication to be sold in tablet form. *AP/Wide World Photos.*

also in platelets, the part of blood that causes clotting. Blocking this chemical creates an analgesic (pain-relieving) and an anticoagulant (blood-thinning) effect. Vane received the 1982 Nobel Prize in Medicine or Physiology for his discovery.

In 1948, a California doctor named Lawrence Craven noticed that men who took aspirin appeared to have fewer heart attacks. He wrote several articles recommending an aspirin a day for men over forty years old, but few people paid attention to his work. Forty years later, the United States Food and Drug Administration (FDA) approved aspirin for reducing the risk of heart attack and some strokes. In the 1990s, the FDA said that taking aspirin during a heart attack could help save a life.

Development

Thousands of years ago the ancient Romans found that chewing the leaves and bark of the willow tree helped people feel better. In the fourth century BCE, the Greek philosopher and physician

Aspirin Is Not For Everyone

As with all drugs, aspirin should be used with caution. Children who have high fevers, chicken pox, or flu should not be given aspirin without the advice of a doctor because it can cause a rare, but serious illness called Reye's syndrome. Pregnant women should not take aspirin in the last three months of their pregnancy unless a doctor approves it. Large doses of aspirin can cause breathing problems, damage the liver, and result in death, especially in young people.

Aspirin can slow the clotting of blood (the action that stops bleeding and forms a scab following a cut). People who take medicines called anticoagulants (medicines taken to reduce blood clotting) should not take aspirin.

People who have had stomach problems should not take aspirin without their doctor's approval because it can irritate the lining of the stomach. Some drug makers sell aspirin covered with a special coating that can reduce stomach pain.

Hippocrates wrote about a white powder taken from the willow tree. The powder helped cure headaches and other aches and pains.

In the early nineteenth century, scientists learned that a chemical called salicin was found in the bark of the willow tree. Salicin is the active ingredient—the chemical responsible for making the medicine work.

Aspirin was originally made from a form of salicin called salicylic acid. This type of aspirin sometimes caused stomachaches, stomach bleeding, and left a bad taste in the mouth.

In 1897 Felix Hoffman (1868–1946), a chemist at Friedrich Bayer & Company in Germany, mixed salicylic acid with some other chemicals. He found a combination developed by French chemist Charles Frederic Gerhardt (1816–1856), made it stable (unchanging and easy to accurately reproduce) and gave it his father, who had arthritis. It relieved the arthritis pain. Hoffman's artificial version of aspirin was called acetylsalicylic acid. This became the first mass-produced drug in history. Nearly 50,000 tons of acetylsalicylic acid is produced every year all over the world for use in various forms and drugs.

In 1899, Friedrich Bayer & Company gave physicians aspirin to give to their patients. Until 1915 people needed a physician's prescription to buy aspirin. The first aspirin came in powder form. Tablets came a year later. Aspirin quickly became the world's leading drug.

By the end of World War I (1915–18), Friedrich Bayer & Company lost the exclusive right to aspirin's formula. Other com-

Words to Know

Analgesic: A compound that relieves pain without loss of consciousness.

Anticoagulant: A subtance that prevents blood from clotting.

Inflammation: A complex series of events associated with injury or disease that, when combined, serve to isolate, dilute, or destroy the agent responsible and the injured tissue.

Prostaglandin: A fatty acid in the stomach that protects it from ulcerating.

panies quickly copied the formula and sold similar products. A United States court ruled that aspirin was a common (generic) name, which meant that the word could be used by anyone.

Current Issues

Researchers are studying whether aspirin can help prevent certain types of cancer. Possible uses include decreasing breast cancer and cancer of the pancreas rates in women and preventing colon cancer from returning after surgery. Researchers with the National Cancer Institute are investigating whether an aspirin-like drug may be a useful addition to drugs treating cancer of the ovaries (female reproductive organs).

Aspirin's role in fighting serious infections is also under investigation. For example, researchers have shown that aspirin reduces the ability of certain germs to cause sepsis, a blood infection that is often responsible for deaths of persons hospitalized in intensive care units.

* * *

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[*See Also* **Vol. 1, Painkillers.**]

Biochip

Description

A biochip is a device that has some of the features of a computer chip but, instead of doing calculations, it uses living cells (or molecules from living cells) to greatly speed up certain laboratory tests. A typical biochip is a glass or plastic chip or tile a few inches on a side. It has hundreds or even tens of thousands of microscopic droplets of material stuck to its surface like gum on a sidewalk. A computer looks at the chip using a camera. Information from a biochip can be used to learn about the differences between genes, cells, or drugs. It can also be used to study many other questions about cells. Biochips are also called microarrays, where *micro* means "small" and an array is any regular grid, such as a chessboard. The droplets on a biochip are laid down in a checkerboard pattern. A square chip five inches (thirteen centimeters) on a side may have 40,000 or more spots on its surface.

The most common kind of biochip is the DNA microarray, also called a gene chip or DNA chip. Deoxyribonucleic acid (DNA) is the long, coded molecule used by all living things to pass on traits to offspring. DNA also tells each cell how to make all the molecules it needs to live, like a cookbook containing many recipes. The DNA of almost every living thing is at least slightly different from that of every other.

In one type of DNA chip, genes—short pieces of DNA that code for single molecules—are placed on the chip. Since even large molecules are too small to see with the naked eye, millions of copies of each gene can be placed on a tiny spot on the chip.

Scientific Foundations

There are several kinds of DNA chip. This is a simplified explanation of how one kind of DNA chip works. In a DNA chip,

A biochip device designed for medical applications. © *AFP/Corbis.*

each separate spot (also called a probe) contains one type of defective gene. To find out if a person has any of these defective genes in their own DNA, DNA is taken from the person's cells. Copies of the person's DNA are made, and these copies are labeled, meaning that they include a chemical that glows when ultraviolet light (which is invisible to the eye) shines on it. Small drops of liquid containing labeled copies of the person's DNA are then added to the spots on the biochip.

A normal DNA molecule is shaped like a ladder, but the DNA copies being mixed on the biochip are one-sided copies, like a ladder that has been sawed in half lengthwise, cutting every rung in half. When two pieces of one-sided DNA that have matching rungs (or bases, as they are called) meet, they lock or zip together. When this happens, the two pieces of DNA are said to hybridize. If the patient's genes match any of the defective genes that have been put on the biochip, they will attach to (hybridize with) those defective genes.

The chip is then washed to remove any of the person's DNA that has not found a match on the chip. Finally, the chip is placed in ultraviolet light, and a camera records any spots that glow. These are spots where the labeled copies of the person's DNA have matched up with DNA on the chip.

Examining a patient's DNA for defects is called genetic screening. By using a biochip, genetic screening can be done very quickly—all the tests can be done at once, rather than doing hundreds or even thousands of separate tests.

Genetic screening is only one way of using biochips. Another important use for biochips is to study how genes are used by living cells. Each gene tells the cell how to make a certain protein molecule. Cells read the recipe given by the gene by first making another molecule, mRNA, which copies the information in the gene. The mRNA can then go to a place in a cell that will build the molecule that the gene codes for. The more mRNA a cell has for a gene at a particular time, the more it is said to be "expressing" that gene—that is, the more of that particular molecule it is making. Gene expression changes all the time for thousands of genes in every cell.

In the laboratory, scientists can make DNA molecules from the mRNA found in a cell. This matching DNA is called cDNA (complementary DNA). If a biochip has all the genes of an organism dotted on its surface, then cDNA made from the mRNA in a cell can attach to (hybridize with) the genes on the chip. The more a gene is being expressed in the cell, the more cDNA for that gene there will be, and the more that cDNA will stick to the matching genes on the biochip. Spots with more labeled cDNA will glow more brightly under ultraviolet light. In this way, scientists can literally take a snapshot of how the genes in a cell are being expressed at any one time—how much the cell is making, at that moment, of thousands of different substances. This is extremely useful in trying to understand how cancer cells grow and in many other medical problems.

Development

The development of biochips began in the 1990s, when scientists' knowledge of genetics (the science of DNA) and computers made biochips practical. To make a biochip, one must have a way of depositing thousands of microscopic droplets on a surface exactly where they need to go. Ways of handling, multiplying, and reading pieces of DNA are necessary to create biochips, and these techniques were not invented until the 1960s and 1970s.

Early Warning System

Thanks to jet airplanes and global trade in everything from raspberries to beef, viruses can spread more quickly across the world than ever before. Almost every day, the news carries reports of viruses—from the human immunodeficiency virus (HIV, the virus that causes AIDS) to influenza viruses. But it is not always easy to tell which virus is which. They are very small, far smaller than a single cell, and many of them look alike. So British scientists are building a biochip to act as an early-warning system for viruses. They will place pieces of DNA from known viruses on the chip, and add DNA from a virus to be identified. The DNA from the unknown virus will attach to matching DNA on the chip (if any is there). This can quickly show which virus the sample contains.

In 1988, a new company, Affymetrix, decided to combine the methods used to make computer chips with new DNA technologies. Affymetrix's first biochip, a DNA microarray, went on sale in 1996. Today, at least six different companies make a wide variety of biochips.

Current Issues

Biochips are being used today to do DNA screening and to study gene expression in cancer cells, as well as for many other purposes. In 2005, the U.S. Food and Drug Administration approved a biochip test system called the AmpliChip Cytochrome P450 Genotyping Test, made by Roche Molecular Systems, Inc. Cytochrome P450 genes affect how the liver breaks down some drugs. Every person has slightly different P450 genes. The AmpliChip contains different versions of the P450 genes on its surface. DNA from a patient is then added to the chip to see which kinds of P450 genes the patient happens to have. Which P450 genes they have affects how quickly their body breaks down some drugs, including drugs used for depression (sadness that will not go away) and cancer. Patients whose bodies can break down a drug more quickly may need larger drug doses.

Biochips are having an effect on the study of genes almost as great as the effect computer chips had on computing a few decades ago.

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Words to Know

Acquired immune deficiency syndrome (AIDS): An epidemic disease caused by an infection with the human immunodeficiency virus (HIV).

Deoxyribonucleic acid (DNA): The double-helix shaped molecule that serves as the carrier of genetic information for humans and most organisms.

Expression (of gene): In cell biology, to make a protein according to the recipe in a DNA molecule. A gene that is used to make a protein is said to be expressed.

Genetic screening: Examination of a person's genes to see if they contain any defects.

Human immunodeficiency virus (HIV): The virus that causes AIDS (acquired human immunodeficiency syndrome); HIV stands for human immunodeficiency virus.

Microarray: A regular grid of spots containing biological molecules or living cells on the surface of a biochip.

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[*See Also* **Vol. 3, Biodetectors; Vol. 1, Bioinformatics; Vol. 3, DNA Computing; Vol. 1, Genetic Testing, Medical.**]

Bioethics

Description

Ethics are the rules or principles of right and wrong. The word is also used to mean careful, reasoned thinking (philosophy) about right and wrong. “Bio” is Greek for “life,” so the word “bioethics” means the philosophy of right and wrong in matters involving living things.

There are several types of bioethics. The most common type is medical ethics, or the study of what choices are wrong or right in the practice of medicine. This type of bioethics dates back to the Hippocratic oath in ancient Greece. This oath says that a doctor promises to do no harm to patients and to behave rightly in other ways. A shortened version of the Hippocratic oath is still taken by people graduating from medical schools around the world. Today, however, medical ethics is more complicated than ever before, because biotechnology has made many new choices possible. For example, is it wrong to change human genetic material in order to cure inherited diseases? What about to make children taller or lighter-skinned? There is deep disagreement in society over these questions and many others like them.

Scientific Foundations

Science explains facts—what exists, or what may happen if certain choices are made. Science does not tell whether the choices we make about facts are right or not. Although philosophers argue about where the sense of right and wrong comes from—whether it is an insight into eternal truth, an illusion, or something else—most scientists, doctors, and philosophers agree that science cannot answer ethical, moral, or religious questions. For example, biology can describe every microscopic detail of a two-day-old human

Stem Cell Research IS Pro-Life
(My ♥ daughter's life!)

Protestor supporting stem cell research in hopes that cures for diseases like her daughter's juvenile diabetes can be found. *Getty Images.*

embryo, but it cannot settle the argument about whether an early-stage human embryo is a full-fledged "person" with legal rights.

Development

The Hippocratic Oath was probably written by the Greek physician Hippocrates (pronounced hip-OCK-rah-tees) or one of his students about 2,400 years ago. Several other codes of medical behavior were written in the following centuries. World War II (1939–1945) triggered much thought about medical ethics because of the actions of the Nazi regime, which ruled Germany from 1933 to 1945. Nazi beliefs combined politics, claims about biology, and violence. The Nazis killed medical patients they thought unworthy of life, considered Germans a "master race," sterilized tens of thousands of people whom they thought should not have children, and justified killing Jews and Gypsies on the grounds that those groups were biologically inferior. Doctors were involved in the mass killings at Auschwitz and the other extermination camps run by the Nazis. Nazi doctors also performed experiments on

Considering Deliberate Extinction

Smallpox is a disease that has killed millions of people throughout human history. Smallpox vaccine (a medicine that prevents people from getting smallpox) first became available in the nineteenth century, yet smallpox is thought to have killed several hundred million people in the twentieth century. The United Nations' World Health Organization began a campaign to eradicate (eliminate) smallpox in 1967. By the late 1970s, the goal had been accomplished; the last natural case of smallpox occurred in 1977. However, samples of smallpox virus, the tiny organism that causes the disease, remained in laboratories. In 1978, a photographer was killed by smallpox being handled in a laboratory. Today, the only known stocks of smallpox are held by the Russian government and by the U.S. Centers for Disease Control. The World Health Organization is considering destroying these last known stocks so that smallpox can never threaten human lives again. Others say that to deliberately drive any species to extinction, even a species of virus, would be wrong.

human beings. After the war, doctors, scientists, and others realized that a new way of thinking about the morality of medical behavior was necessary in light of what the Nazis had done.

After World War II, in the United States and elsewhere, however, medical experiments continued to be done on people without their knowledge. Some prisoners and black men were allowed by researchers to suffer diseases after treatments were discovered in order to see what would happen if they were not treated. In 1979, a U.S.-government appointed group issued the famous Belmont Report, which laid down a new framework of rules for medical ethics that is used to this day.

At about the same time, modern genetics, including genetic engineering, was beginning to raise a host of new bioethical questions. These continue to be discussed, becoming more numerous and complicated as genetic technology rapidly presents us with more choices.

Current Issues

Current issues in bioethics include abortion (early termination of a pregnancy), assisted suicide, genetic engineering of plants and animals, possible genetic engineering of human beings, human cloning (making genetic copies of tissues or organisms), animal rights, extreme life support (keeping sick and injured people who

Words to Know

Smallpox: A deadly viral disease that was eradicated in the 1970s. Today the virus only exists in closely-guarded samples held by the American and Russian governments.

Vaccine: A product that produces immunity by inducing the body to form antibodies against a particular agent. Usually made from dead or weakened bacteria or viruses, vaccines cause an immune system response that makes the person immune to (safe from) a certain disease.

Virus: A very simple microorganism, much smaller than bacteria, that enters and multiples within cells. Viruses often exchange or transfer their genetic material (DNA or RNA) to cells and can cause diseases such as chickenpox, hepatitis, measles, and mumps.

have no hope of recovery alive artificially, stem cell research (research into cells that are undifferentiated, that have the potential to develop into other cells), the participation of psychologists in torture or harsh interrogation, contraception (preventing pregnancy), and many more.

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[*See Also* **Vol. 3, Animal Research and Testing; Vol. 1, Human Cloning; Vol. 1, Genetic Discrimination; Vol. 2, Genetically Modified Organisms; Vol. 2, Terminator Technology.**]

Bioinformatics

Description

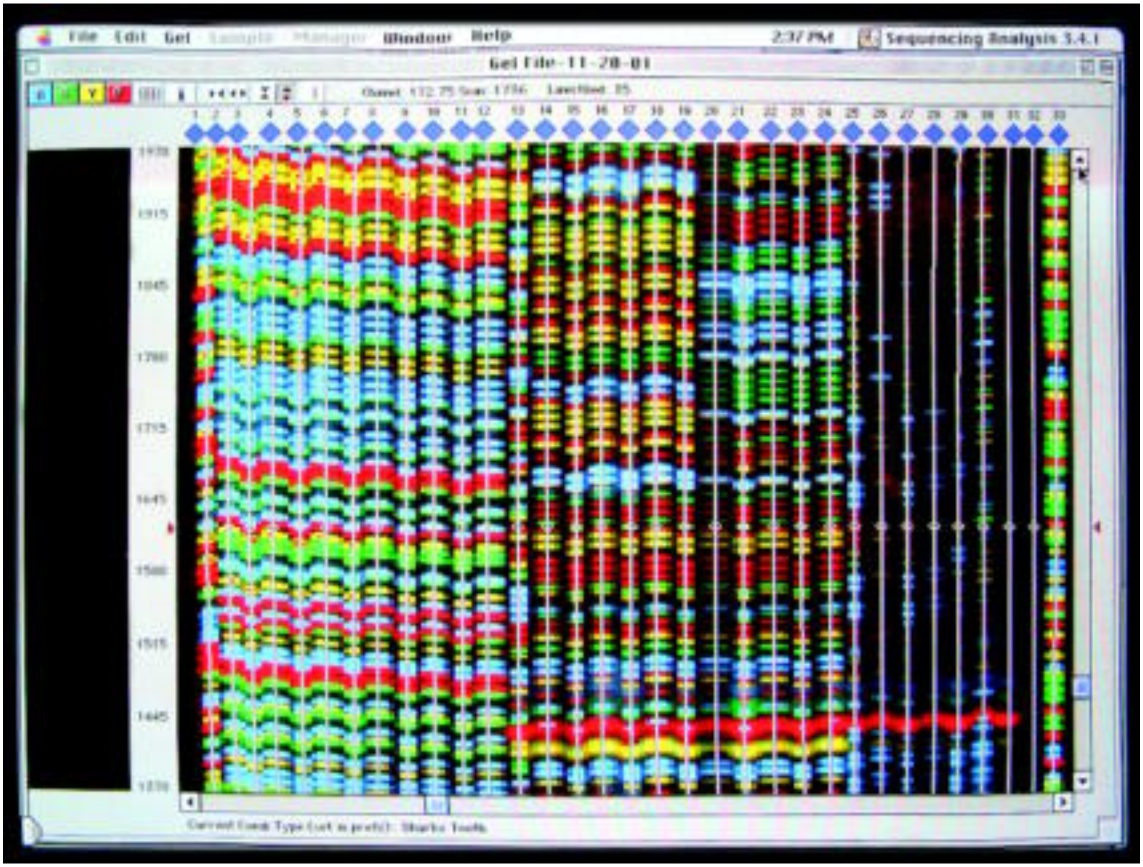
Bioinformatics refers to the storage and analysis of biological information using computers. Once scientists were able to isolate and sequence a particular organism's genetic sequence, there arose a need to store and analyze the information. With bioinformatics, scientists can compare data from the genetic material of a variety of living things, from tiny bacteria to large organisms, such as humans.

Bioinformatics has a number of uses. Collecting and analyzing data from people in different parts of the world gives scientists insight into how humans have evolved over time. Medical researchers can study genetic diseases and try to find effective treatments. Law enforcement officials keep large databases of genetic information obtained from criminals or collected at crime scenes. The information from these databases can be used to identify a victim or perpetrator of a crime.

Computer databases are at the heart of bioinformatics. Once information is stored in an organized way, mathematical formulas called algorithms can be written as part of the software that is used to analyze the data. Algorithms permit searches to be carried out to reveal regions of the genetic material that are similar to one another. In addition, algorithms have been constructed that can search and compare different databases. This was an important development, since different databases are not always compatible with one another.

Scientific Foundations

The genetic material of a cell is stored in the form of molecules of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), most often in the cell's nucleus. Vast amounts of information can be generated from determining the sequences of an organism's DNA and RNA. Chromo-



somes are pieces of DNA that pass on traits to offspring. Chromosomes are made of thousands of genes. Each gene is a tiny section of DNA that tells a cell how to do one particular job. Genes tell cells how to produce a certain protein, which are molecules that carry out all the functions of cells.

At the beginning of the 1980s, genetic material could be sequenced, but the process was long and tedious. Then, the sequencing of DNA was automated, which greatly increased the speed of sequencing. By 1989, the first genome sequence of an entire organism, a bacterium called *Haemophilus influenzae*, was published. The following year, the Human Genome Project was begun. The goal of the project—to sequence the complete collection of genes found in a single set of human chromosomes—was achieved in 2001. Since then, the realm of bioinformatics has grown to include the analysis of protein structure, information

Computer image of DNA from an automated DNA sequencing machine. Once DNA sequences are stored on computers, they can be analyzed using the techniques of bioinformatics. *T. Bannor/ Custom Medical Stock Photo.*

Bioinformatics and Privacy

Bioinformatics is valuable tool in basic science, medicine, and law enforcement. However, there is also a concern that the databanks of information on people's genetic make-up could be tampered with or used maliciously. The bioinformatic databases that are maintained by law enforcement agencies, such as the Federal Bureau of Investigation (FBI), have many safeguards and levels of user authorization in place to restrict their use. Nonetheless, computer databases are vulnerable to corruption, and so constant vigilance is necessary to protect the data. The use of bioinformatics by organizations such as insurance companies is also a concern. Disclosure of medically relevant information is allowed in the insurance industry. Critics are worried that health or life insurance might be denied based on a person's DNA profile.

concerning the function of genes and proteins, information on metabolism (the chemical reactions that take place in an organism) and other cell pathways, and data from medical studies.

Development

The need for database-analysis tools became urgent as more and more DNA sequences were unraveled. By the time the Human Genome Project finished its work, the amount of genetic information was enormous, and databases had been created in the United States (GenBank), Europe (EMBL), and elsewhere (DNA Database of Japan) to hold the data and analyze the DNA sequences. In addition, new tools were available to analyze the activity of an organism's genetic material at a given point in time. Chief among these latter techniques are microarrays.

A microarray, or biochip, is an arrangement of genetic material on a solid base, usually glass, plastic, or tile. It can analyze samples of DNA from one chosen subject at a time. The microarray's genetic material acts as a genetic test, and can bind to the sample DNA to reveal certain characteristics about the subject.

One microarray can reveal the activity of hundreds of genes at one time. Thus, tremendous amounts of information can be quickly compiled just for one microorganism. Without the analytical tools of bioinformatics, the information collected from microarrays and in large-scale studies such as the Human Genome Project could not be deciphered and, for all practical purposes, would be useless.

Words to Know

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

DNA sequence: The sequence of base pairs in a DNA molecule.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Genome: A complete set of the DNA for a species.

Human Genome Project: The joint project for designed to decode the entire human genome (hereditary information).

Microarray: A regular grid of spots containing biological molecules or living cells on the surface of a biochip.

Protein: Complex molecules that cells use to form most of the structures and control chemical reactions within a cell.

Current Issues

Since the completion of the sequencing of the human genome in 2001, bioinformatic examination of the data has begun. There is a tremendous amount of work to do to, first, identify all of the estimated 30,000 genes contained within the genome; to determine the proteins coded for by the genes; and, ultimately, to determine the structure and function of the proteins.

It is hoped that this level of understanding of the human genome will lead to strategies to correct defects that arise during the construction of proteins that are the basis of many diseases, such as sickle cell anemia, cystic fibrosis, and Alzheimer's disease.

Not only that, the use of microarrays that contain the genes associated with certain diseases and disorders can enable physicians to screen a patient's DNA for defects, a process called genetic screening. By using a microarray, genetic screening can be done very quickly; all the tests can be done at once, rather than doing hundreds or thousands of separate tests.

Bioinformatics has also become an important law enforcement tool. Analysis of DNA collected at the scene of a crime can provide valuable information on the identity of the culprit or victim. A sample of blood, hair, or semen from a crime scene can be quickly and very accurately linked (or not) with a suspect. Newly introduced DNA evidence has also exonerated many prisoners who were imprisoned for crimes they did not commit.

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[*See Also* **Vol. 1, Biochip; Vol. 1, DNA Sequencing; Vol. 1, Gene Banks.**]

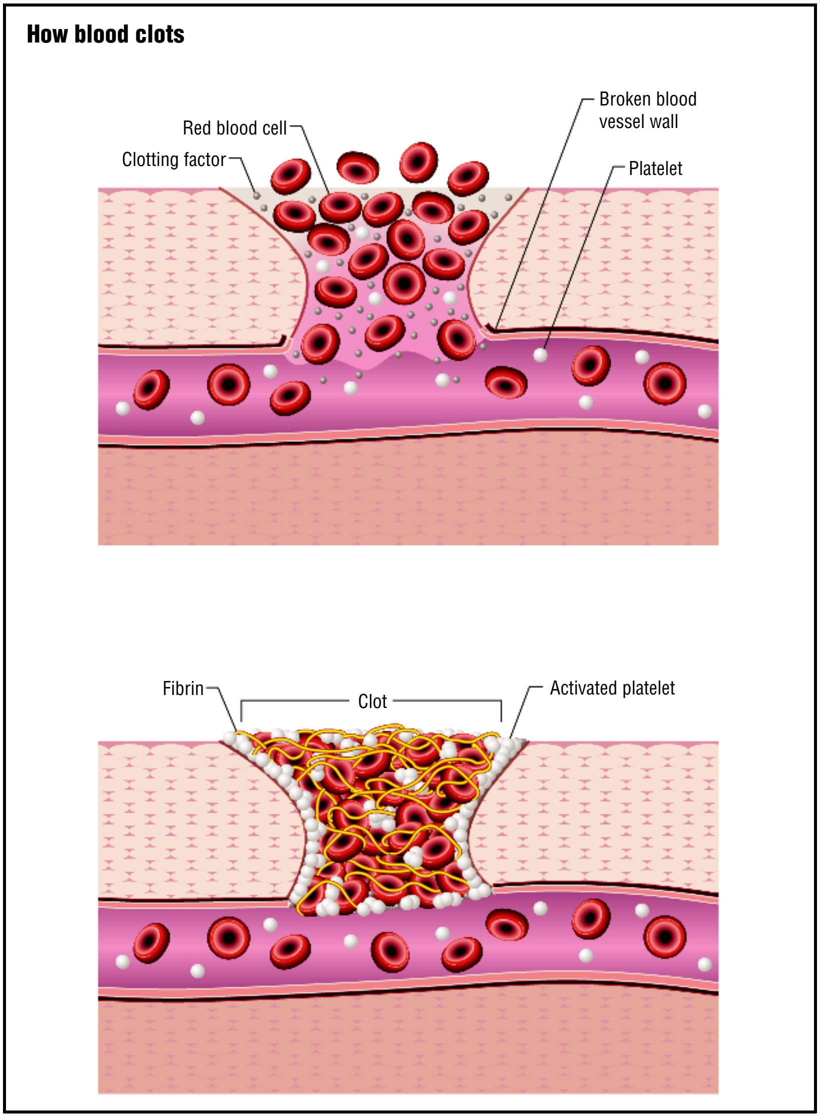
Blood-Clotting Factors

Description

Clotting, also called coagulation, is what happens when liquid blood turns into a solid (clot). This is life-saving when it stops bleeding from a wound. Blood-clotting factors are substances in the blood that help coagulation happen. There are eleven major clotting factors, numbered using Roman numerals from I to XIII (1 to 13—the numbers III and VI are not used, for historical reasons). There are some unnumbered clotting factors as well, such as von Willebrand factor.

The body's response to bleeding has four basic steps. The first is vascular constriction, which is the muscular tightening or squeezing of the injured blood vessels to reduce the flow of blood. The second is the formation of a temporary plug or clot by platelets, which are small cells in the blood that stick to the fibers in tissue exposed by a wound. The formation of a platelet plug or clot triggers the third step, which is the formation of a longer-lasting clot by a stringy material called fibrin. The fourth step is the removal of the fibrin clot during healing. This is done by a substance in the blood called plasmin.

The third step, the formation of the long-lasting fibrin clot, is the most complicated. It involves a series or cascade of reactions involving the blood-clotting factors. Each blood-clotting factor affects the action of the next factor, like dominoes falling in a row. This series of events is called the clotting cascade. Because some factors later in the clotting cascade also affect the action of factors earlier in the cascade, the cascade is actually more like a network of dominoes falling in a complex pattern that loops back on itself. This article does not discuss the details of the clotting cascade.


How blood clots
Red blood cell
Clotting factor
Broken blood vessel wall
Platelet
Fibrin
Clot
Activated platelet

How blood clots. When a blood vessel is cut, platelets are activated, which starts a chain of events that produces fibrin and results in the formation of a clot. *Illustration by GGS Inc.*

Scientific Foundations

Clotting factors are proteins, a type of large molecule (cluster of atoms) made by cells. Proteins are made by cells by stringing together chains of smaller molecules called amino acids. The order in which a cell chains together amino acids to make a particular protein is set by a recipe or list of instructions in a DNA molecule. DNA (deoxyribonucleic acid) is a long molecule shaped like a twisted tape or ladder; the rungs of this chemical ladder act like letters in a coded message. Three chemical "rungs" in a DNA

Clotting in Court

In 2005, a court case was heard in Pennsylvania, *Kitzmiller versus Dover Area School District*. The case was brought because the Dover board of education had said that high-school biology students must hear an official statement that the theory of evolution is flawed and that students should know about an alternative theory called intelligent design (ID). ID says that life is too complex to be explained naturally. During the trial, a molecular biologist named Michael Behe cited the blood-clotting cascade as evidence for ID because it is, he said, ''irreducibly complex''—must have all its parts to work. Other scientists who spoke in court disagreed. The judge sided with scientists who argued against ID, and then ruled against the school district's anti-evolution statement.

molecule specify one amino acid in the recipe for building a protein. DNA is found in almost all cells, with a few exceptions such as platelets and red blood cells, and contains codes for thousands of different proteins. When DNA is damaged or defective, a protein will be made incorrectly or perhaps not at all.

The short sections of DNA (genes) that code for the blood-clotting factors VIII, IX, and XI (eight, nine, and eleven) are damaged in some people. This means that their blood does not clot properly, and it is hard for them to stop bleeding. They may even bleed to death from a small wound. This disorder is called hemophilia (pronounced hee-mo-FEEL-ee-ah), and people who have it are called hemophiliacs.

Development

Scientists did not fully understand blood clotting until the late twentieth century. The function of platelets was identified in 1882. Various blood factors were discovered starting in the early 1900s and continuing through 1963. The use of Roman numerals to name the factors was agreed upon in 1955. Factor XIII was that last to be discovered, in 1963. The ways in which the clotting factors affect each other took many years longer to unravel.

Current Issues

Today, genetic engineering of bacteria is used to make factors VIII and IX to give to hemophiliacs so that their blood will clot normally. These manufactured factors are called “recombinant” factors because genes from human beings are recombined with the genes in non-human cells in order to produce cells that will produce the factors.

Words to Know

Clotting: The solidification of blood in response to a wound: coagulation.

Coagulation: The solidifying or clotting of blood. Beneficial when used by the body to seal a wound; harmful if it occurs inside blood vessels.

Fibrin: A protein that functions in the blood-clotting mechanism; forms mesh-like threads that trap red blood cells.

Hemophilia: A genetic disorder in which one or more clotting factors are not released by the platelets; causes severe bleeding from even minor cuts and bruises.

Platelet: A piece of a cell that contains clotting factors.

Vascular constriction: The muscular contraction or narrowing of blood vessels in respond to injury.

To make a recombinant clotting factor, the gene in human DNA that tells cells how to make that factor is isolated. Then it is inserted into cells from hamster kidneys or ovaries (female sex organs). These cells are grown in culture (in laboratory dishes) in large numbers. The cells make the clotting factor according to the human DNA recipe that has been given to them. The factor is separated from the cell culture and purified.

Factor VIII is unstable—that is, it does not last long in storage or in the body. Research is under way to find ways of making recombinant factor VIII that is more stable. They are also seeking ways to make it more cheaply and to change it so that it does not trigger the immune systems of some hemophiliacs.

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[*See Also* **Vol. 1, Insulin, Recombinant Human; Vol. 2, Recombinant DNA technology.**]

Blood Transfusions

Description

A blood transfusion is a medical procedure in which blood or parts of blood are put into a person's body. A tiny tube is placed into a vein, and the new (transfused) blood flows through it. A blood transfusion can take several hours, depending on how much blood a patient needs. Transfusions are usually given when an injury, accident, sickness, or surgery causes a person to lose too much blood. People who receive cancer-killing drugs (chemotherapy) or who have certain blood diseases may need ongoing blood transfusions.

The blood used for transfusions comes from people who volunteer to donate their blood. Each year more than eight million people volunteer to give blood. Some people donate their own blood before surgery. A transfusion that uses a person's own donated blood is called an autologous blood transfusion. If a transfusion uses blood donated from someone other than the patient, it is called an allogeneic transfusion.

Scientific Foundations

Blood is grouped into four different types: A, B, AB, and O. Physicians try to match the blood in a transfusion to the patient's specific blood type. It is very important that the type of blood used in the transfusion works with the patient's own blood type. Dangerous side effects can occur if a person gets the wrong type of blood. People with AB blood can safely receive any other type of blood. These people are called universal recipients. Type O blood is considered safe for anyone, and is often used in emergencies. People who have type O blood are called universal donors.

Shelves of donated blood at a blood bank. © *Martin Schutt/dpa/Corbis.*

Blood can be broken down into many parts. The three parts of blood most often used for transfusions are red blood cells, plasma (a yellow, watery liquid that holds cells), and platelets (sticky cells that form clots to help stop bleeding). A transfusion may use only one of these parts, or it may be a whole blood transfusion using all of them.

Development

The earliest blood transfusion took place in the mid-1600s, a few years after English physician William Harvey (1578–1657) discovered how blood flowed through the body. In 1665, English physician Richard Lower (1631–1691) discovered that giving dogs blood from other dogs helped keep them alive.

More than a hundred years later, American physician Philip Syng Physick (1768–1837) completed the first human-to-human blood transfusion, but he never published the details of his work. British obstetrician James Blundell (1791–1878) is usually credited

Monitoring Blood Banks

In 1947, the American Association of Blood Banks (AABB) was formed to give the public and physicians more information about blood donation. In 1953, the group set up a national clearinghouse that supervised the exchange of blood between blood banks. Today the central clearinghouse is called the National Blood Exchange. In 1957, the AABB formed a committee to create and monitor rules for blood banking. The first rule book, *Standards for a Blood Transfusion Service*, was published a year later in 1958.

with reporting the first human blood transfusion. In 1818, Dr. Blundell gave blood to a patient who was bleeding heavily after giving birth, using blood from her husband. Over the next several years, Dr. Blundell did ten more blood transfusions, and five of them helped his patients.

Various transfusion experiments occurred throughout the late 1880s. One physician tried to use germ-killing chemicals (antiseptics) to prevent transfusion-related infections. Others looked for a substitute for blood, and gave transfusions using milk or salt water (saline). These experimental blood transfusions caused many deaths.

Blood transfusions became much safer in 1900, when Austrian physician Karl Landsteiner (1868–1943) discovered that not all blood was the same. He grouped blood into three groups: types A, B, and C. (Type C was later renamed type O.) Dr. Landsteiner's research won him the Nobel Prize for Medicine or Physiology in 1930. Blood type AB was discovered two years later by researchers Alfred von Decastello (1872–) and Adriano Sturli (1873–1964).

In the early 1900s, researchers found ways to store donated blood for several days after collection. The first official blood bank was started in 1932 in a hospital in Leningrad, Russia. Five years later, Bernard Fantus set up the first United States hospital blood bank at Cook County Hospital in Chicago, Illinois. In 1940, the United States government established a nationwide blood collection program with the American Red Cross. By the end of World War II in 1945, the American Red Cross had collected thirteen million units of blood.

As transfusions became more popular, scientists wondered if certain diseases could spread through the blood. In 1943, American physician Paul Bruce Beeson (1908–) found that a person had caught

Words to Know

Acquired immune deficiency syndrome (AIDS): An epidemic disease caused by an infection with the human immunodeficiency virus (HIV).

Autologous blood transfusion: A transfusion a patient's own blood.

Hemophilia: A genetic disorder in which one or more clotting factors are not released by the platelets; causes severe bleeding from even minor cuts and bruises.

Hepatitis: General inflammation of the liver; may be caused by viral infection or by excessive alcohol consumption.

Human immunodeficiency virus (HIV): The virus that causes AIDS (acquired human immunodeficiency syndrome), an epidemic disease.

Plasma: The liquid part of the blood. Contains clotting elements.

Platelets: Irregularly shaped disks found in the blood of mammals that aid in clotting the blood.

hepatitis (infection of the liver) through a blood transfusion. In 1984, the human immunodeficiency virus (HIV) was discovered to cause acquired immune deficiency syndrome (AIDS), an incurable disease that affects the body's defense system. In 2002, researchers learned that West Nile virus could spread through transfusions. West Nile virus is caught through a mosquito bite. It can cause flu–like symptoms and, in severe cases, brain swelling (encephalitis). All these discoveries initiated the implementation of new tests to screen blood for disease-causing viruses.

Current Issues

A major concern regarding blood transfusion is whether the recipient will catch a disease from the donated blood. Advanced screening tests have dramatically reduced this risk. People who wish to donate blood must pass a strict screening exam. Only healthy people over age seventeen are allowed to give blood. The donated blood is then put through a number of different screening tests to check for diseases, bacteria, and other dangerous substances. Modern surgeries use fewer blood transfusions than operations performed several years ago, and there are new drugs to reduce the need for ongoing transfusions.

The most common transfusion reaction is a life-threatening event called a hemolytic transfusion reaction. This reaction occurs if the patient is given the wrong type of blood, and it causes the body to kill red blood cells. Hemolytic transfusion reactions are the most common causes of transfusion-related deaths.

In some cases, a blood transfusion may cause the body's defense system to continually produce a large number of inflammation-causing substances. This can lead to organ failure.

Blood is a valuable substance. Despite the number of blood donors, blood shortages often occur. Blood banks need a large supply of blood, so there is plenty on hand if a large number of people become sick at once time.

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[*See Also* **Vol. 1, Blood-Clotting Factors.**]

Bone Marrow Transplant

Description

Bone marrow is the spongy tissue inside bones. The marrow contains special cells called stem cells. Stem cells make three kinds of blood cells: white blood cells to fight infection, red blood cells to carry oxygen, and platelets to help the blood clot (stop bleeding). A bone marrow transplant replaces damaged bone marrow with healthy marrow that can produce blood cells.

Bone marrow transplants are often used as medical treatments for people who have cancer. Some cancers treated with a bone marrow transplant are leukemia (a cancer that begins in the bone marrow), lymphoma (a cancer of the immune system cells), and multiple myeloma (a cancer that begins in white blood cells).

Cancer occurs when cells divide too quickly. These cells can, over time, damage organs. To treat cancer, doctors use anticancer drugs called chemotherapy, or high-energy rays called radiation. These treatments destroy cells that divide too quickly. Bone marrow cells divide quickly, so they can also be destroyed by these treatments. Without bone marrow, the body cannot make enough blood cells to fight infection, carry oxygen to tissues, and help blood clot.

Scientific Foundations

There are three types of bone marrow transplants:

- Syngeneic—When a person receives bone marrow from his or her identical twin.
- Allogeneic—When a person receives bone marrow from a parent, brother or sister, or from an unrelated donor.

Sterile hospital room of a patient who had a bone marrow transplant. Transplant recipients are extremely vulnerable to infection following the surgery. © *Custom Medical Stock Photo, Inc.*

- Autologous—When a person receives his or her own bone marrow. The bone marrow is collected before the person has chemotherapy or radiation. It is frozen until the person is finished with treatment.

Bone marrow is removed from the donor through a process called harvesting. The donor gets medicine called anesthesia that

Donating Bone Marrow

Healthy individuals between the ages of eighteen and sixty can join the National Marrow Donor Program (NMDP). The NMDP maintains a list of donors and resources necessary to help doctors match them with patients who need a bone marrow transplant.

Two different types of bone marrow donations are collected. The first is a marrow donation that removes marrow from the donor's hip bone. This is a surgical procedure. The second type of donation collects peripheral (circulating) blood cells (PBSC). This procedure involves inserting a needle into the donor's arm and removing their blood, passing it through a machine that takes out the PBSC and returns the remaining blood back into the donor's other arm. In both types of collection, the donor's marrow and blood supply usually return to normal in a few weeks.

prevents him or her from feeling any pain. Bone marrow is removed from the donor's bone through a needle. Doctors usually take the bone marrow from the donor's hip bone.

To transplant the bone marrow, the doctor first removes the damaged bone marrow from the patient. Then, the doctor puts a needle into the patient's vein to put the new bone marrow into the person's blood. The healthy bone marrow travels to the holes inside the bones. Once there, it will start making white blood cells, red blood cells, and platelets. It can take as long as a year or two for the new bone marrow to be able to fully produce new blood cells.

Development

In the 1950s, scientists began to notice that the chemotherapy and radiation used to treat patients with cancer damaged bone marrow. Scientists thought it might be possible to treat this damage by giving the patients healthy bone marrow from another person.

The first human bone marrow transplants were done in France during the 1950s. The patients had been exposed to high levels of radiation. The bone marrow transplants did not work because the patients' bodies rejected the foreign bone marrow.

Successful bone marrow transplants were not possible until 1958, when a French doctor named Jean Dausset made an important discovery about the human immune system. He described substances in the body called human leukocyte antigens (HLA). Dausset found that the immune system uses HLAs to identify cells that belong in the body and stop the immune system from attacking them.

Words to Know

Allogeneic: Of the same species.

Anesthesia: Inducing sleep so that an individual can undergo surgery or remain unconscious until a crucial and painful period of a surgical procedure has passed.

Autologous: A transfusion or transplant of a patient's own blood, bone marrow or tissue.

Bone marrow: A spongy tissue located in the hollow centers of certain bones, such as the skull and hip bones. Bone marrow is the site of blood cell generation.

Chemotherapy: The use of chemicals to kill dangerous cells in order to treat diseases, infections, and other disorders such as cancer.

Human leukocyte antigens (HLA): A type of antigen present on white blood cells; divided into several distinct classes; each individual has one of these distinct classes present on their white blood cells.

Leukemia: A cancer of the blood-producing cells in bone marrow.

Lymphoma: A cancer of the blood cells that are part of the active immune system.

Platelets: Irregularly shaped disks found in the blood of mammals that aid in clotting the blood.

Radiation: Energy in the form of waves, or particles.

Red blood cells: Hemoglobin-containing blood cell that transports oxygen from the lungs to tissues. In the tissues, the red blood cells exchange their oxygen for carbon dioxide, which is brought back to the lungs to be exhaled.

Rejection: An event that occurs when the body'ss defense (immune) system attacks a transplanted organ.

White blood cells: Leukocytes. Cells that help fight infection and disease.

Doctors now take a blood sample from the donor and the recipient to check whether the their HLA antigens match before doing a bone marrow transplant. This reduces the chance that the recipient's body will reject the new bone marrow. An identical twin or close relative is most likely to be a close match.

Initially, doctors could only perform bone marrow transplants on identical twins because twins are the closest genetic match. The first successful bone marrow transplant not done on identical twins was in 1968. A child with a severe immune system disease received bone marrow from his sister.

Doctor Edward Donnall Thomas of the Fred Hutchison Cancer Research Center in Seattle, Washington, helped develop the bone marrow transplant as a treatment for leukemia. He was the first to successfully transplant bone marrow from one unrelated person to another. Thomas won the Nobel Prize in 1990 for his work.

In 1984, Congress passed the National Organ Transplant Act. It helped set up a national list, called a registry, of donors. This registry has helped people who need a bone marrow transplant find a well-matched donor.

Current Issues

One problem doctors need to overcome when doing bone marrow transplants is graft-versus-host disease (GVHD). This happens when white blood cells in the donor's marrow see the cells inside the recipient's body as foreign and attack them. GVHD can damage the patient's liver, intestines, and skin. Sometimes, doctors give the patient drugs to suppress, or hold back, the immune system before the bone marrow transplant to prevent GVHD.

A new transplant method uses a smaller amount of bone marrow from the donor. It is called the mini-transplant. The patient is given lower doses of radiation and chemotherapy to destroy only some of their bone marrow. Cells from both the donor and the patient work together in the patient's body to destroy the cancer.

* * *

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[*See Also* **Vol. 1, Anti-Rejection Drugs; Vol. 1, Cancer Drugs; Vol. 1, Chemotherapy Drugs.**]

Bone Substitutes

Description

Bone substitutes are materials that mimic or imitate the natural composition of bone. They are used in the medical repair of an injury or defect in bone. The bone substitute must be similar in structure and function to natural bone, so that the introduced material will not break down within the body.

Injuries, such as a broken bone that does not fully heal or bone loss due to cancer, can require surgical intervention. In many cases, natural bone can be taken from another site in the patient's body or from the skeleton of a cadaver (dead body) and reused at the site of the problem. These procedures are called autografting (AW-toe-graft-ing) and allografting (AL-o-graft-ing), respectively. However, these options may not always be available. Then, in approximately one percent of cases, an artificial bone substitute can be used.

Scientific Foundations

Bone substitutes can be made of metal, plastic, gypsum, calcium sulfate, collagen (the most prevalent protein in bone), and ceramics (a nonmetallic material such as clay that has been heat-treated to make it very hard and resistant to corrosion). While these provide suitable material, they can be brittle and prone to breakage, are unable to grow if the rest of the skeleton increases in size, and cannot change their shape if excess force is applied to them.

Because of these disadvantages, a field of science called bone tissue engineering came into being. Scientists working in this field try to blend biology and engineering principles to create living substitutes for natural bone. Cells that are the precursor to bone

Scientist preparing a liquid form of bioactive glass. This specialized material is used as a substrate, a kind of miniature scaffolding for growing human bone cells. *James King-Holmes/Photo Researchers Inc.*

are taken from the patient or obtained from another source. These cells are mixed with molecules that function in bone formation. The mixture is added to a three-dimensional support. Examples of support material include mixtures of metals, such as titanium alloy and chromium-cobalt. Some supports degrade over time, as the bone forms around it. Ultimately, the new bone is implanted into the patient.

The subsequent incorporation of the implanted bone into the adjacent bones is aided by some of the traditional bone substitutes. The best example is collagen, which enhances the fusion of the graft with existing bone.

The creation of bone substitutes used in dental implants has been aided by biologic modifiers—substances that change the activity of cells involved in forming the substitute material. One modifier is calcium carbonate, which is obtained from coral. Indeed, the structure of coral is similar to the structure of bone, with open regions interspersed in the web-like interconnections. Another modifier is the non-carbon material recovered from cattle bones. Other modifiers are synthetic (artificial); examples include

The Coming Explosion in Bone Replacement Surgery

As the people in developed countries like the United States, Japan, and France, get older, bone and joint problems are increasing, according to the World Health Organization (WHO). WHO, with the support of the United Nations, has declared 2000-2010 as the Bone and Joint Decade. Currently, bone-related joint diseases account for about 50 percent of all long-term health concerns in people over sixty-five years of age, and 40 percent of women above fifty years of age suffer a bone fracture. Currently, there are approximately 2.2 million bone transplants performed every year. As the population continues to age, the prevalence of bone-related problems will increase, along with the costs of treating them.

glass-like materials and a compound called methylmethacrylate (METH-ill-meth-ACK-rill-ate). Methylmethacrylate is particularly useful as a bridging compound between two regions of bone, serving to connect the regions together. Other modifiers exist and new ones continue to be developed.

Development

Medical researchers are attempting to better understand the process of bone formation, which is complex and influenced by a variety of genetic and external environmental factors. The aim is to speed up the formation of bone on the supporting material and to ensure that the developing bone continues to be well-supplied with blood. Currently, maintaining a blood supply is a problem.

One area of this type of research involves trying to create bone in laboratory conditions using stem cells. Stem cells are cells found in the bone marrow and other locations in the bodies of embryos and adults that have the potential to form any kind of tissue. (Bone marrow is soft tissue inside bones where blood cells are made.) If successful, this approach could allow large quantities of bone to be made and available for the thousands of bone repair surgeries performed every year in the United States.

New bone substitute materials also are being developed. The aim is to minimize the body's immune response to the implanted material and so lessen the possibility of rejection. (Rejection happens when the immune reaction is so strong that the new tissues or materials must be removed.) One example of these new materials is a paste made of bone morphogenetic proteins—glycoproteins

Words to Know

Bone: The major component that makes up the human skeleton. Bone produces blood cells and functions as a storage site for elements such as calcium and phosphorus.

Calcium: An essential macro mineral necessary for bone formation and other metabolic functions.

Collagen: A type of protein that comprises connective tissue; infiltrates the liver in cirrhosis.

Graft: A transplanted tissue.

Joint: A place of movement where bones meet.

Lipid: A family of biochemical compounds that are oily, fatty, or waxy and cannot dissolve in water.

Protein: Complex molecules that cells use to form most of the structures and control chemical reactions within a cell.

Stem cell: An unspecialized cell that can divide to form other types of specialized cells in the body. Stem cells give rise to cells that have specialized form and function such as nerve or muscle cells.

(GLI-ko-PRO-teenz) that naturally function in bone formation. When surgically implanted, the paste can help heal a broken bone.

Current Issues

A major issue concerning modern-day bone substitutes is the creation of substitutes that essentially mimic real bone. One approach seeks to create the substitute outside the body, and then implant the engineered bone inside the body. Another approach tries to bring about the construction of new bone inside the body by supplying genes that are essential in the process. Certain viruses are useful to introduce genes into other cells; this ability could be used to deliver genes that are crucial to bone formation to the site of injury. Genes may also be delivered inside a lipid vesicle—a sphere whose exterior is made of lipid. Fusion of the lipid vesicle (VES-ik-ul) with the lipid of a host cell causes the genes inside the vesicle to be released and, hopefully, to be incorporated into the cells' genetic material. Lipids are organic compounds, like fats and oils, that can't be dissolved in water.

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[*See Also* **Vol. 1, Bone Marrow Transplant; Vol. 1, Collagen Replacement; Vol. 1, Insulin, Recombinant Human; Vol. 1, Skin Substitutes.**]

Botox

Description

Botox® is a pure form of the botulism toxin called *Clostridium botulinum* type A. Physicians use it in very small amounts to relax muscle contractions for neurological disorders, such as cerebral palsy, and other disorders with muscle contractions (in which muscles tighten uncontrollably). Originally, it was used for the treatment of crossed eyes.

As a product of Allergan, Inc., it is a cosmetic procedure that has grown in popularity. Cosmetic surgeons inject it under the skin and into muscles to temporarily reduce facial wrinkles. It is used to remove frown lines of the nose and forehead, and wrinkles around the eyes and mouth. Patients typically see results within a week, although longer response times may occur for smaller injections. The injections can be repeated when the effect wears off, usually between three to twelve months. Dosages are kept low because repeat users usually build up an immunity to Botox®. Side affects, such as allergic reactions, are rare. Some patients may see some bruising around the injected area. The most common side effect is a headache.

Scientific Foundations

The *C. botulinum* toxin is a poisonous bacterium (a one-celled living thing that sometimes causes disease). It can cause paralysis and death when eaten in contaminated food. However, *C. botulinum* can also heal people when used in a purified form by controlling muscle contractions.

The bacteria and spores (forms of the bacteria that can grow into new bacteria) of *C. botulinum* are found in soils of farmlands and forests and sediments of streams, lakes, and coastal waters. The

Woman receiving a cosmetic Botox® treatment for facial wrinkles. © *Rick Gomez/ Corbis.*

spores are also found on fruits and vegetables and in shellfish. The bacteria and spores cannot hurt humans. It is when they grow that the toxin is produced, which is the substance that harms people. There are seven varieties of *C. botulinum*, designated by the letters A, B, C, D, E, F, and G. Types A, B, E, and F cause human botulism, while types C and D cause animal botulism. Type G is found in soil primarily in Argentina but has not yet caused botulism.

Development

In 1989, the U.S. Food and Drug Administration (FDA) approved a pure form of the botulism toxin as a medicine called Botox®. It treated two types of muscle problems with the eyes. The toxin weakened the muscle but did not affect surrounding muscles. Since that time, Botox® has been used to treat bad muscle posture and tension, muscle spasms of the neck and shoulder, uncontrollable blinking of the eyes, clenching of the jaw muscles, bladder muscle contractions, and nerve disorders.

The American Society for Aesthetic Plastic Surgery reported that 1.6 million treatments of Botox® were given in 2001, an increase of 46 percent over 2000. On April 15, 2002, the FDA approved *C. botulinum* toxin type A for the temporary relief of frown lines between the eyebrows after a scientific study showed that test subjects that used Botox® had wrinkles reduce or disappear within thirty days.

Botox® Parties

The use of Botox® has become so popular that people are hosting Botox® parties all over the United States. They are often modeled after Tupperware® parties. At these parties, food and drinks are served while men and women gather together to buy products relating to Botox®. Activities also include doctors providing injections of Botox®. The parties help introduce people to Botox® and provide new patients to doctors. Some people say they feel more at ease to receive Botox® when friends are around. However, some doctors do not agree with Botox® parties because they feel such procedures should be performed in regulated environments such as medical facilities.

Additional information about Botox® can be found at the web sites of the American Academy of Dermatology (http://www.aad.org/), the American Society for Dermatologic Surgery (http://www.asds-net.org/), and the American Society for Aesthetic Plastic Surgery (http://www.surgery.org/).

Current Issues

The use of Botox® concerned many people because it is one of the most poisonous materials known. When it was first introduced in the United States, many people did not like the idea of being injected in the face with poison. However, it also gained support from large numbers of users because it was an easy procedure with quick results. It is also relatively inexpensive when compared to cosmetic surgeries.

Scientific studies show that 0.000001 milligram per one kilogram of body weight will cause death in people half the time. However, according to the Food and Drug Administration, its safety record is very good.

Botox® can leak into nearby areas causing temporary weakness of muscles. Around the eye, for example, the problem can cause difficulty in lifting the eyelids or double vision. People who use Botox® may develop allergic reactions or immunity to it. Injections in the same area may cause the muscle to weaken, what is called dimpling. Botox® has been used for many years so its long-term effects are well known. Some patients may develop difficulty breathing, swallowing, or talking. Pregnant women should not take Botox® because the risks to the fetus are not known.

Problems have occurred when unqualified people inject Botox® incorrectly into patients. Many times Botox® has been injected in salons, gyms, motel rooms, and other unsanitary areas that may

Words to Know

Bacterium: A single-celled microorganism that can cause disease (singular of bacteria).

Toxin: A poison that is produced by a living organism.

not be safe. The FDA recommends that all Botox® treatments be taken in a sterile environment from a physician who is certified in facial cosmetics.

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[*See Also* **Vol. 1, Collagen Replacement; Vol. 3, Cosmetics; Vol. 3, Government Regulations.**]

Cancer Drugs

Description

Anticancer drugs, also called chemotherapy drugs, are divided into several groups based on how they affect a cancer cell. Strictly speaking, cancer treatment is based on either stopping the division of the cancer cell or killing the cancer cell.

Cancer is the second leading cause of death in the United States. Academic institutes and pharmaceutical companies continue to conduct extensive research on the causes and treatments of various types of cancer.

Scientific Foundations

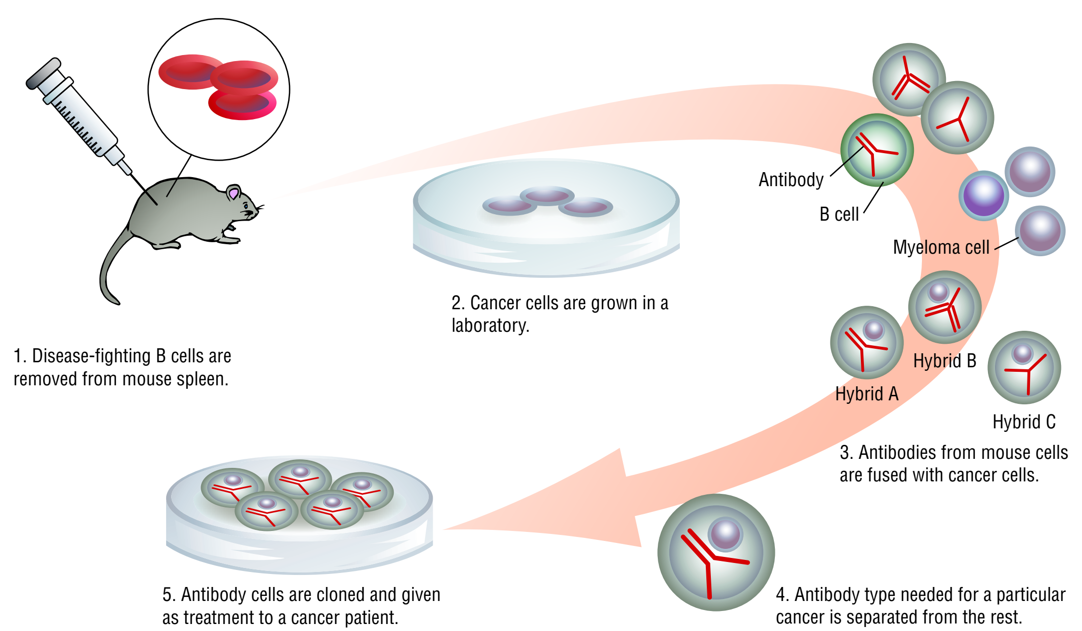
Cancer develops when the cells of an organ or tissue grow out of control. Normal cells grow, divide and then die. Cancer cells, instead of dying, out-live normal cells and continue to divide abnormally.

Cancer cells develop due to damage in the genetic material, or deoxyribonucleic acid (DNA), in cells. When DNA becomes damaged, normal cells repair it; however, in cancer cells, this mechanism of repair is somehow disrupted. Cancer can be inherited or it can be caused by something in the environment, like smoke, toxins, or sunlight (more specifically ultraviolet [UV] rays).

Most cancer cells eventually will become a tumor (a mass of abnormal cell growth) and can either be defined as malignant (cancerous) or benign (non-cancerous). An exception to this is leukemia; this cancer involves blood cells and circulates through the blood. When cancer cells travel to other parts of the body (metastasizes), the cancer can be life threatening.

Cancer drugs

How monoclonal antibodies are made


Antibody
B cell
Myeloma cell
Hybrid A
Hybrid B
Hybrid C
1. Disease-fighting B cells are removed from mouse spleen.
2. Cancer cells are grown in a laboratory.
3. Antibodies from mouse cells are fused with cancer cells.
4. Antibody type needed for a particular cancer is separated from the rest.
5. Antibody cells are cloned and given as treatment to a cancer patient.

How cancer drugs called monoclonal antibodies are created for a particular patient. *Illustration by GGS Inc.*

Anticancer drugs interfere with the growth of tumor cells, eventually causing their death. Common chemotherapy drugs used in various cancers include doxorubicin (Adriamycin) in breast cancer, often administered with cyclophosphamide (Cytoxan); paclitaxel (Taxol) in lung cancer; and fluorouracil (5-FU) in colon cancer. Some are given only as injections. Others, such as imatinib (Gleevec) for leukemia are taken by mouth in tablet or liquid form.

Most chemotherapy drugs fall within one of two classes, cycle-specific drugs and non-cycle specific drugs. Cycle-specific drugs act only at specific times in the duplication of a cell, while non-cycle specific drugs act any time within the cell cycle. The drugs are often given in combination in order to achieve the maximum number of opportunities to disrupt cancerous cell growth during the cell cycle.

Traditional chemotherapy has a wide-ranging effect. Although it kills cancer cells, it can also affect surrounding normal cells, particularly those that have a tendency to divide quickly, such as cells in the stomach lining, or the hair follicles (where the hair grows). This is what produces unpleasant side effects such as

Beans and Leaves

It is hard to pinpoint when the first cancer drug was used, as many native peoples have historically used herbs to treat some forms of cancer. Scientists now know that some herbs, tea, and bugs contain natural products that specifically target cancer cells. For example, the plant product cholchicine, isolated from the autumn crocus flower, was one of the first of plant products shown to reduce tumors in laboratory mice.

nausea and hair loss. These side effects are treatable, and are reversible after completing the course of chemotherapy.

Approximately 400 million new white blood cells are formed in the body every hour. Found mainly in the bone marrow, they are the main defense against infection. During cancer treatment, white blood cells are destroyed at a rate the body cannot replace and this is why bone marrow transplants are sometimes used after chemotherapy. Blood stem cell transplants have revolutionized cancer therapy by replacing bone marrow transplants after chemotherapy. This means patients can undergo higher doses of chemotherapy with a greater possibility of recovery.

Drugs known as monoclonal antibodies are also available to treat some types of cancer. Monoclonal antibodies attack cancer cells in much the same way that the body's immune system attacks invading organisms. These drugs have find particular receptors on the surface of cancer cells, and block or destroy the receptor sites, thus interfering with processes, such as cell growth, that are vital to the tumor's survival.

Development

The first practical anticancer drug was discovered accidentally. It was noticed that sulfur mustard gas, a toxin used as a weapon in World War I (1914–18) caused myelosuppression (bone marrow suppression). Although this gas was not used in World War II (1939–45), a considerable stock of mustard gas was stored in the Mediterranean area. An accident in the Italian port of Bari involving the leakage of one of the canisters restarted interest in the myelosuppressive effects of nitrogen mustard, leading to clinical trials in lymphoma patients. Nitrogen mustard was found to react chemically with DNA and damage it. After scientists learned to understand the structure of DNA, this gave rise to understanding

Words to Know

Benign: A growth that does not spread to other parts of the body. Recovery is favorable with treatment.

Chemotherapy: Use of powerful drugs to kill cancer cells in the human body.

Deoxyribonucleic acid (DNA): The double-helix shaped molecule that serves as the carrier of genetic information for humans and most organisms.

Metastasize: The spread of cancer from one part of the body to another.

Stem cell: An unspecialized cell that can divide to form other types of specialized cells in the body. Stem cells give rise to cells that have specialized form and function such as nerve or muscle cells.

Tumor: An uncontrolled growth of tissue, either benign (noncancerous) or malignant (cancerous).

how substances can inhibit DNA from reproducing. These include various thymine and purine forms. These agents initially dominated the development of cancer drugs.

Current Issues

There are many exciting developments in cancer therapy. At the moment, doctors know about a number of genes (called oncogenes) that predispose someone towards developing cancer. (A gene is a piece of DNA that tells cells how to do a particular job.) The understanding of the complete gene map of cancer will allow doctors to spot early those who are likely to develop the condition. Another exciting development in cancer therapy involves the understanding of the pathways that lead to resistance to certain therapies. By rationally combining therapies, it is possible to reverse the resistance to therapy in some patients. In other patients, it is possible to look for certain biomarkers (distinctive biological conditions) that increase the likelihood of success of therapy. Thus we are approaching an era where individualized medicine can be a reality.

Angiogenesis, or blood vessel growth, is also on the cutting edge of cancer therapy. Tumors encourage blood vessel growth (angiogenesis) by secreting substances called growth factors. Growth factors can encourage small blood vessels (capillaries) to grow and feed into the tumor, thus allowing the transfer of nutrients necessary for the growth of the tumors. Angiogenesis is a mechanism that transitions a small harmless cluster of cells to a large tumor. Angiogenesis is also required for the spread or migration of a tumor. Single cancer cells can break away from an established solid tumor, enter the blood vessel, and be carried to a distant site, where they can implant and begin the growth of a secondary tumor. New drugs that prohibit angiogenesis are currently undergoing testing in humans, and are promising new therapies.

Monoclonal antibodies are drugs that have been researched since the 1980s. Antibodies are substances that animal bodies naturally use to attack foreign cells. Antibodies that target a patient's particular type of cancer cells can be created in the laboratory and used as a cancer treatment. Although there is much potential in the research, only a few drugs had become available as of 2006.

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[*See Also* **Vol. 1, Bone Marrow Transplant; Vol. 1, Chemotherapy Drugs; Vol. 1, Genetic Testing, Medical; Vol. 1, Germline Gene Therapy; Vol. 1, Stem Cell Lines.**]

Chemotherapy Drugs

Description

The word "chemotherapy" usually means the use of strong medicines to treat cancer. Cancer is a disease caused by the body's own cells. Most cells reproduce by dividing in two and then regrowing, but cancer cells are cells that have changed so that they do not stop dividing. They may form colonies that grow until vital organs are destroyed, killing the patient.

There are several ways of treating cancer. All seek to kill cancer cells without harming cells in the rest of the body. Radiation, surgery, and chemotherapy are the three most common treatments for cancer. Chemotherapy is used against almost all cancers. There are dozens of anti-cancer chemotherapy drugs in use.

Scientific Foundations

All cells, including cancer cells, contain DNA (deoxyribonucleic acid), a long, twisted, tape-like molecule that contains information the cells needs to function and reproduce. During reproduction, a cell must first make a copy of its own DNA. It then splits in two, giving one copy to one of its descendants and the other copy to the other descendant. To copy its DNA and divide, a cell must go through a series of stages or phases called the cell cycle. Most chemotherapy drugs are designed to interfere with some phase of the cell cycle and prevent cancer cells from reproducing.

According to the system of grouping used by the American Cancer Society, there are seven main types of chemotherapy drugs:

Alkylating agents. These chemicals attach to DNA strands and make them unable to untangle themselves and split down the middle, a necessary step in DNA copying. If this process goes

Chemotherapy drug being injected into the arm of a cancer patient. *Custom Medical Stock Photo. Reproduced by permission.*

wrong, a cell will usually kill itself. Although most normal healthy body cells also need to divide, cancer cells usually divide more often, and so can be killed by lower concentrations of alkylating agents than the rest of the body.

Anti-metabolites. These chemicals interfere with attempts by the cell to build new DNA. They resemble one of the chemicals used to build DNA but cannot be so used, and so waste the efforts of the cell trying to build DNA.

Anthracyclines. These chemicals insert themselves directly into double-sided strands of RNA and DNA, distorting them and preventing them from being duplicated.

Corticosteroid hormones. These hormones reduce cancer growth, stimulate appetite, and ease skin rashes caused by other cancer drugs. Since these substances also occur naturally in the body, they are sometimes not counted as chemotherapy drugs.

Mitotic inhibitors. These drugs, derived from plants, prevent the cell from dividing after it has duplicated its DNA.

Nitrosoureas. These substances are similar to alkylating agents. They interfere with the action of substances that repair DNA. Because these drugs can cross into brain cells, they are often used to treat brain tumors.

Topoisomerase inhibitors. Topoisomerases are substances that help the DNA maintain its proper shape. (It is not randomly tangled.) By inhibiting topoisomerases—preventing them from working—these

Clinical Trials

For a new medicine to be legal for use on patients, it must be proven effective by scientific testing. But how can a new medicine, such as a chemotherapy drug, be proven effective in the first place without using it on patients? The answer is the clinical trial. This is a controlled experiment in which the new drug or treatment is used on a small number of volunteers. There are three sizes of clinical trial, called phases: Phase I uses about 50 people, Phase II about 200, and Phase III several thousand. If the drug proves safe and effective in each phase, it goes on to the next. After Phase III, it is approved for general use. There are many clinical trials in progress, and patients may ask to be included, hoping to be early users of an effective new treatment. For example, on September 7, 2006, the National Cancer Institute's clinical trials website (www.nci. nih.gov/clinicaltrials) listed 3,622 clinical trials in progress for different cancer treatments.

drugs disrupt DNA shape and interfere with copying of DNA in cell reproduction.

Development

Strangely, the first chemotherapy drug was a chemical warfare agent. Scientists noticed that the deadly chemical called mustard gas (a sulfur compound not related to table mustard) tended to kill cells of the body's lymphatic system (part of the immune system). Some cancers—lymphomas—are cancers of lymphatic cells. In the mid 1940s, scientists tried treating lymphomas in mice with mustard gas. They found that they could shrink the cancers (temporarily) without killing the mice. The first step toward chemotherapy had been taken.

In the 1950s and 1960s, research into many other kinds of anticancer chemical continued. Combination therapy—using more than one chemotherapy drug at once, to interfere with cancer cells in several different ways at the same time—was first tried in 1965. Today, combination therapy is standard for both cancer and AIDS.

In the 1980s, research into the substances called monoclonal antibodies began. Antibodies are small molecules that stick to specific targets. Other cells in the immune system then attack whatever the antibodies have stuck to. Antibodies can be made that will stick to the cancer cells in a patient's body but not to other cells. This causes the patient's own immune system to attack the cancer cells. Although this method of fighting cancer has been intensively researched since the 1980s, as of 2006 only a few were yet in regular use for certain cancers. For example, one type of monoclonal

Words to Know

Clinical trial: A government-approved experiment using human volunteers to see if a new drug or other treatment for a disease is safe and effective.

Combination therapy: The use of more than one drug at the same time in treating a disease. Combination therapy is standard in both AIDS and cancer.

Monoclonal antibodies: Antibodies produced from a single cell line that are used in medical testing and, increasingly, in the treatment of some cancers.

antibody, called trastuzumab, has been approved for treating breast-cancer patients whose cancer cells are of a certain type.

Current Issues

Chemotherapy drugs seek to kill cancer cells. But since cancer cells are body cells that have gone awry, they are not very different from healthy cells. Drugs that kill cancer cells therefore also tend to injure other cells. In short, chemotherapy makes people sick. It interferes with the immune system, which opens the patient to infections. Many chemotherapy drugs cause nausea and vomiting. Other side effects include damage to the liver, kidneys, and heart; diarrhea or constipation; bleeding; and dulled mental activity. These side effects not only make patients miserable, but limit how much of the anti-cancer drug they can take without dying. Researchers are always looking for new chemotherapy drugs that are more effective against cancer while causing fewer side effects.

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[*See Also* **Vol. 1, Cancer Drugs; Vol. 3, Government Regulations; Vol. 1, Pharmacogenetics.**]

Cloning, Human

Description

To clone a human is to create a person with the exact same deoxyribonucleic acid (DNA—the molecule inside a cell that contains its genetic information) as another person. A clone is made using a woman's egg that has had its genetic material removed and a cell from another adult.

The difference between a clone and someone born naturally to two parents is their genes. People who are born naturally have genes from both their mother and father. A cloned person only has genes from the person who donated the cell.

Scientific Foundations

In nature, a sperm from a man fertilizes an egg from a woman. The sperm carries one set of genes from the man, and the egg carries another set of genes from the woman. The genes are kept in tightly coiled structures called chromosomes, which are contained in the nucleus of the sperm and egg. The nucleus is the part of the cell that directs most of its functions. The fertilized egg begins to divide to form an embryo (a human being in the earliest stages of development). The embryo contains two complete sets of chromosomes: one from the father and one from the mother.

Sometimes a fertilized egg can naturally divide into two separate embryos. Each embryo is exactly same as the other genetically. They are called identical twins. Scientists can also create identical twins in a lab by separating an early embryo into two individual cells. After each cell has divided and grown, they are implanted into a woman's uterus (the organ in a woman's body that holds the growing fetus). This is a kind of basic cloning.

X
STOP
Human Cloning
KFEM

Demonstrator in Korea protesting the practice of cloning human cells at a medical school in Seoul, South Korea. *AP/Wide World Photos.*

Scientists can clone a person in a lab using an egg that has had its genetic material removed and an adult cell. They have to use an electric shock to get the egg and cell to divide and form an embryo.

Hello Dolly

In 1997, scientists at the Roslin Institute in Scotland announced that they had cloned a sheep named Dolly. To make Dolly, the scientists put a cell taken from the udder (a milk-releasing gland) of a six-year-old female sheep into an egg taken from another sheep. They first removed the nucleus, which contains the genetic material, from the egg. Then they used an electric shock to get the cells to divide. The scientists had to try 277 times before Dolly was born. Dolly was an identical copy of the female sheep that donated the cell.

Dolly caused great debate around the world. Many people were afraid her birth would lead to the practice of human cloning. Since her birth, scientists cloned goats, cows, sheep, cats, and many other animals. But they still had not cloned a human being.

Development

Scientists have been able to clone a living creature since the 1950s. The first animal to be cloned was a tadpole. In 1997, scientists cloned the first mammal—a sheep named Dolly.

Cloning humans is much more controversial than cloning animals. In 2001, scientists from a Massachusetts company called Advanced Cell Technology produced cloned embryos. In 2002, a religious group called the Raelins said they had cloned a human, but it turned out to be a hoax.

Somatic cell nuclear transfer (SCNT) is a method scientists use to make a human clone. A somatic cell is any type of cell in the body that is not a sperm or egg cell. (These are called germ cells.) It contains a complete set of chromosomes in its nucleus. In SCNT, scientists first remove the nucleus from an adult somatic cell. They then insert it into an egg that has had its own nucleus removed. Without its nucleus, the egg does not have its own genetic material. All of the genetic material comes from the somatic cell.

Scientists then use a small electric shock to get the cells to divide. The cells keep dividing and growing until they form an embryo. That embryo is implanted in a woman's uterus. If the process is a success, the embryo would grow into a human being.

If a person were cloned, he or she would look very much like the cell donor, but they would not be identical. Even though the DNA is removed from the egg that is used to make the clone, there is still some genetic material left in the egg's mitochondria (the

Words to Know

Chromosome: A thread-shaped structure that carries genetic information in cells.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Embryo: A stage in development after fertilization.

Ethical: Having to do with morality, or what is perceived as being the right thing to do.

Mitochondria: An organelle that specializes in ATP formation, the ''powerhouse'' of the cell.

Somatic cell: Cells that are part of the body but are not in the germline (able to pass their DNA on to future generations). Any type of cell in the body that is not a sperm or egg cell.

Tumor: An uncontrolled growth of tissue, either benign (noncancerous) or malignant (cancerous).

Uterus: Organ in female mammals in which the embryo and fetus grow to maturity.

structures in cells that provide energy for the cells). A cloned person would receive a small amount of DNA from the egg donor.

Current Issues

There is still a question as to whether governments and scientists will allow human cloning. Some countries want to ban the practice. In 2005, the United Nations called for a total ban on all types of human cloning. United States President George W. Bush also sought a total human cloning ban. Many doctors and scientists believe that it is not ethical (having to do with morals, or what people believe is right) to clone a human being. They believe it is playing with nature in a way that humans do not have the right to do.

The science of cloning is still far from perfected. More than ninety percent of all cloning attempts fail. Cloned animals have had many health problems. They have a higher risk of infection and tumors (abnormal growths of tissue that may be cancer) and several died very young. There is a chance that cloned humans would also have many health problems, and that most would not even survive.

Some scientists are pushing to continue with therapeutic cloning, however. In therapeutic cloning, only an embryo is cloned. It is destroyed before it can grow into a full human being. The goal of therapeutic cloning is to get stem cells. These cells can grow into every type of cell and tissue in the body. They can be used to treat disease or to grow new organs for people whose organs have been damaged.

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[*See Also* **Vol. 2, Animal Cloning; Vol. 1, Bioethics; Vol. 1, Germline Gene Therapy; Vol. 3, Government Regulations; Vol. 1, Nuclear Transfer; Vol. 1, Stem Cells, Embryonic; Vol. 1, Therapeutic Cloning.**]

Collagen Replacement

Description

Collagen (KAHL-uh-jen) is a protein that makes up the bulk of connective tissue. (Proteins are the primary components of living cells.) This tissue helps protect and support organs, and holds body parts together. Examples of connective tissue include cartilage, ligaments, and tendons. Collagen is also a component of bones and teeth.

Collagen has a critical role in the body. For example, it helps maintain the strength of blood vessels, which is important since blood moves through the vessel under pressure from the pumping heart. Collagen's importance is reflected by the abundance of this protein in the mammals. Approximately 40 percent of the total protein in humans is collagen.

In the skin, the collagen and keratin found in the dermal layer (the inner layer of skin) are responsible for skin's strength and elasticity. As humans age, collagen tends to degrade. The reduced skin strength can lead to the formation of the skin folds called wrinkles. People seeking to restore their youthful skin tone can choose to have a cosmetic treatment in which collagen is re-introduced into the skin by injection with a needle.

Scientific Foundations

The shape of collagen is consistent with its support function.

Typically, collagen is long and appears as an arrangement of parallel fibers that form a spiral. A collagen fiber is formed when three strands of linked amino acids wind together to produce a triple helix (HEE-liks) or spiral. (Amino acids are the building blocks of proteins.) Adjacent spirals associate with each other to produce a structure that is similar to linked strands of rope. This

Scientist using a machine that crushes bones from cows. The crushed bones will be used to make a collagen replacement gel. © *Roger Ressmeyer/Corbis.*

structure creates a strong and inflexible molecule that is ideal for resisting forces that would deform proteins of different shapes.

Collagen differs from other proteins with respect to the amino acids it contains and their arrangement. Almost one-third of a collagen molecule is the amino acid glycine (GLI-ceen). A significant

Collagen Safety

Collagen obtained from the skin of cattle is a popular replacement for human skin tissue. It is called bovine collagen. Bovine and human collagens are very similar in amino acid composition and three-dimensional structure. However, the regions near the ends of the collagen strands do differ, which can cause an allergic reaction when bovine collagen is introduced into the human body. To minimize this risk, cattle are raised under clean conditions to reduce their risk of infection, and the end regions of the collagen are removed during the purification process. As a result, allergic reactions are now quite rare.

amount of the amino acid proline (PRO-leen) also is present is each collagen molecule. Collagen also contains hydroxyproline (HIGH-droxie-PRO-leen) and hydroxylysine (HIGH-droxie-LIE-seen), amino acids not common in other proteins. These last two amino acids are modified after being produced by the addition of a hydroxy (OH) group.

These amino acid modifications require the presence of vitamin C. People who don't get enough vitamin C in their diets often have malformed collagen and defective connective tissue. The disease scurvy is an example of the results of vitamin C-related collagen malformation.

Development

Collagen means "glue producer." The term arose from the age-old practice of boiling skin and other body parts of animals to create glue. Collagen-based glues were used in Egypt thousands of years ago, and helped form the bows of Native Americans over 1,000 years ago. The discovery of archeological specimens that still contain deposits of collagen-based glues attests to the longevity of collagen.

In addition, collagen's resilience is useful in the treatment of burns and in cosmetic procedures. Collagen replacement therapy can restore a youthful appearance to the skin. However, some people can develop an allergic reaction to the introduced collagen. In one cosmetic procedure, collagen is injected at the desired sites to eliminate skin lines and wrinkles. Because the collagen degrades over time, repeated injections are required to maintain the skin tone. In another procedure, collagen can be implanted in the dermal layer of the skin.

Aside from its importance to the body, collagen has been exploited commercially. For example, in a liquid, collagen strands will tend to separate from one another to form gelatin. When

Words to Know

Collagen: A type of protein that makes up connective tissue.

Cosmetic: Preparation or procedure intended for beautifying the body.

Protein: Complex molecules that cells use to form most of the structures and control chemical reactions within a cell.

Skin: The largest organ of the body that provides a protective covering for internal structures and helps regulate body temperature.

flavored and sweetened, it can be served as a dessert. Collagen does not contain many of the amino acids that are essential for human health, and so has little nutritional value.

Current Issues

The support, strength, and adhesive properties of collagen have been known for a long time. These aspects are as important now as they were centuries ago. What has changed in recent times is the cosmetic use of collagen. This has spurred efforts to maximize collagen purity, since an allergic reaction to the introduction of collagen is an undesirable side effect of its use. Medical uses of modified collagen for drug delivery and in tissue engineering are being investigated.

* * *

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[*See Also* **Vol. 1, Bone Substitutes; Vol. 1, Botox; Vol. 3, Cosmetics; Vol. 1, Skin Substitutes.**]

Corticosteroids

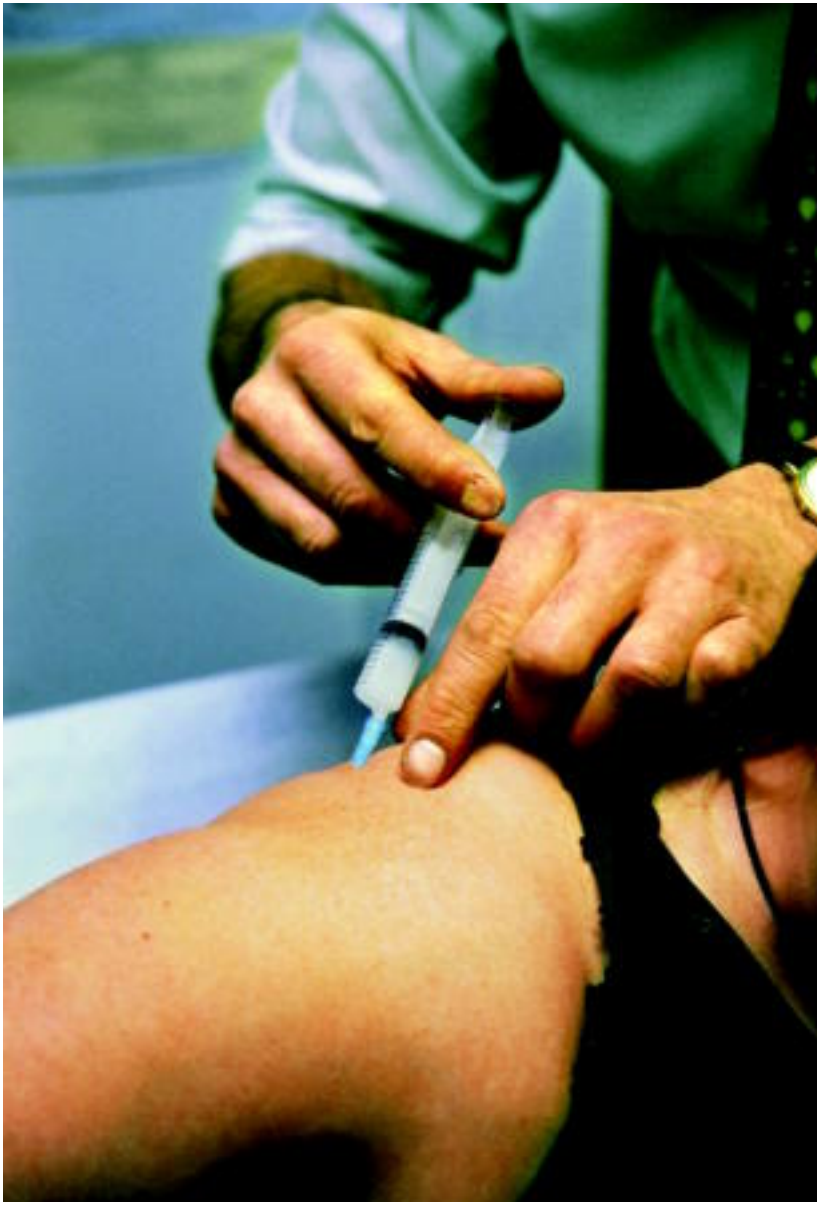
Description

Corticosteroids are a class of hormones. Hormones are chemicals produced by one body tissue and then transported somewhere else in the body, where they cause a response. For this reason, hormones are sometimes called “chemical messengers.” Corticosteroids are produced in the adrenal glands, which sit on top of the kidneys. These hormones are responsible for a variety of physical responses. Corticosteroids reduce inflammation, the body’s response to injury or disease that causes swelling and pain. They are involved in the immune response (in which the body fights off foreign substances, like germs) and the stress response. Corticosteroids also regulate metabolism (how the body breaks down food) and levels of salts in the blood.

Two of the most important types of corticosteroid hormones are cortisol and aldosterone. Cortisol controls the breakdown of carbohydrate, fat, and protein in foods and has an anti-inflammatory effect (reducing pain and swelling). Aldosterone controls the body’s water and salt balance, primarily by increasing sodium levels in the kidneys. (The kidneys filter wastes out of the blood and create urine.)

Scientific Foundations

The adrenal glands are two small glands, each sitting on the top of a kidney. These glands have two parts: an outer layer called the cortex and an inner region called the medulla. The adrenal cortex releases hormones directly into the blood. Once in the blood stream, these hormones travel to their target cells. The target cells have a special receptor that binds (attaches) to the specific hormone. This ensures that each hormone only communicates with specific cells



Doctor giving a patient a cortisone shot to treat a shoulder injury. *Antonia Reeve/Photo Researchers, Inc.*

that possess a receptor for that hormone. Once the hormone is bound to the target cell, it triggers a response.

For example, when the body becomes stressed, the pituitary gland at the base of the brain releases ACTH (adenocorticotropic hormone), which triggers the production of cortisol in the adrenal cortex. Cortisol promotes the production of glucose (blood sugar) from nutrients in the liver, thus providing fuel for cells when the body is under stress. When the stressful situation ends, adrenal hormone production returns to normal. The adrenal glands usually produce about 20 milligrams of cortisol per day, mostly in the morning, but they can produce five times that much when needed.

The control of corticosteroid production from the adrenal glands has interested scientists for quite some time. A disease resulting from a lack of circulating corticosteroids was known as early as the mid-nineteenth century. This disease—characterized by weakness, tiredness, and weight loss—is now called Addison's disease. Since early in the twentieth century, it was known that too much cortisol leads to Cushing's syndrome. The symptoms of this disease include obesity, thinning bones, high blood pressure, depression, a round or moon-shaped face, and a hump at the base of the neck.

Today, synthetic (human-made) corticosteroids are used in medicine to imitate or boost naturally occurring steroids. They are available in a variety of forms: inhalants, lotions, pills, and injections.

Development

In 1948, American chemist Edward Calvin Kendall (1886–1972) and American physician Philip Showalter Hench (1896–1965) discovered a compound that had anti-inflammatory activity and reversed the symptoms of rheumatoid arthritis (a disease that causes painful joints). This compound, which they named cortisone, was a form of corticosteroid.

Their patient, a middle-aged woman with rheumatoid arthritis (RA), was suffering from severe pain and joint swelling. She was given a series of experimental cortisone injections over several weeks. When the treatment was finished, her symptoms had seemed to disappear. For their contribution to medicine—specifically, their discoveries relating to the hormones of the adrenal cortex—Hench and Kendall, along with Polish-born Swiss chemist Tadeus Reichstein (1897–1996), were awarded the Nobel Prize in Physiology or Medicine in 1950.

In the 1950s, an American chemist synthesized cortisone, but its production involved a very expensive and lengthy procedure. By the end of the 1950s, a process was developed that made cortisone more easily in large quantities. Although corticosteroids were effective in treating various ailments involving inflammation, the reason why they worked was unknown. With further research, this was discovered in the 1980s.

Yams and Hormones

In the 1930s, the cost of progesterone, a hormone used to make corticosteroids, was seven times as expensive as gold. In 1941, American chemist Russell Marker (1902–1995) of Pennsylvania State University found that he could extract a chemical called diosgenin from a Mexican wild yam, and diosgenin could be converted to progesterone in a much less expensive way. The conversion of diosgenin to progesterone is known as the marker degradation. Its discovery led to the mass production of steroidal hormones, including cortisone.

Current Issues

At first, corticosteroids were thought to be a miracle drug because they worked quickly and powerfully for many conditions. Since then, many lives have been saved with corticosteroid treatment. But, as the years passed, it became clear that these powerful drugs also produced unwanted side effects. The most common side effects are weight gain, high blood pressure, thinning of the bones, increased risk of having diabetes (a disease in which the body cannot process blood sugars), increased risk of infection, poor sleep, and eye problems. The risk and severity of side effects increases with increasing doses of the drug.

Doctors have discovered that the risks of these drugs can be reduced when the drugs are used carefully. Patients are treated with the lowest effective dose, and occasionally the treatment is discontinued for a period of time. When a person experiences an acute flare-up, the dosage is increased. In addition, patients are sometimes given local injections of the drug rather than exposing the entire body to the drug's effects.

Corticosteroids are used often as a first line of defense against inflammation and may be used with other therapies. If corticosteroids are given in a large enough dose, the inflammation caused by arthritis or an autoimmune disease disappears. (An auto-immune disease is one in which the body attacks its own tissues.) However, recent research shows that, in most cases, low doses of corticosteroids alone may be enough to reduce inflammation. Today, non-steroidal anti-inflammatory drugs, or NSAIDs, are most commonly used to treat patients with rheumatoid arthritis (RA). Low-dose corticosteroid treatment of RA, although effective, is controversial because of its adverse side effects.

Words to Know

Adrenal glands: Two glands located next to the kidneys. The adrenal glands produce the hormones epinephrine and norepinephrine and the corticosteroid hormones.

Cortisol: A hormone involved with reducing the damaging nature of stress.

Cushing syndrome: A disorder in which too much of the adrenal hormone, cortisol, is produced; it may be caused by a pituitary or adrenal gland tumor.

Hormone: A chemical substance produced by the body. Hormones are created by one organ of the body but they usually carry out functions in other organs or parts of the body.

Progesterone: Hormone secreted by the female reproductive organs, used in birth control medicine.

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[*See Also* **Vol. 3, Amino Acids, Commercial Use; Vol. 1, Arthritis drugs; Vol. 1, Painkillers.**]

C-Reactive Protein

Description

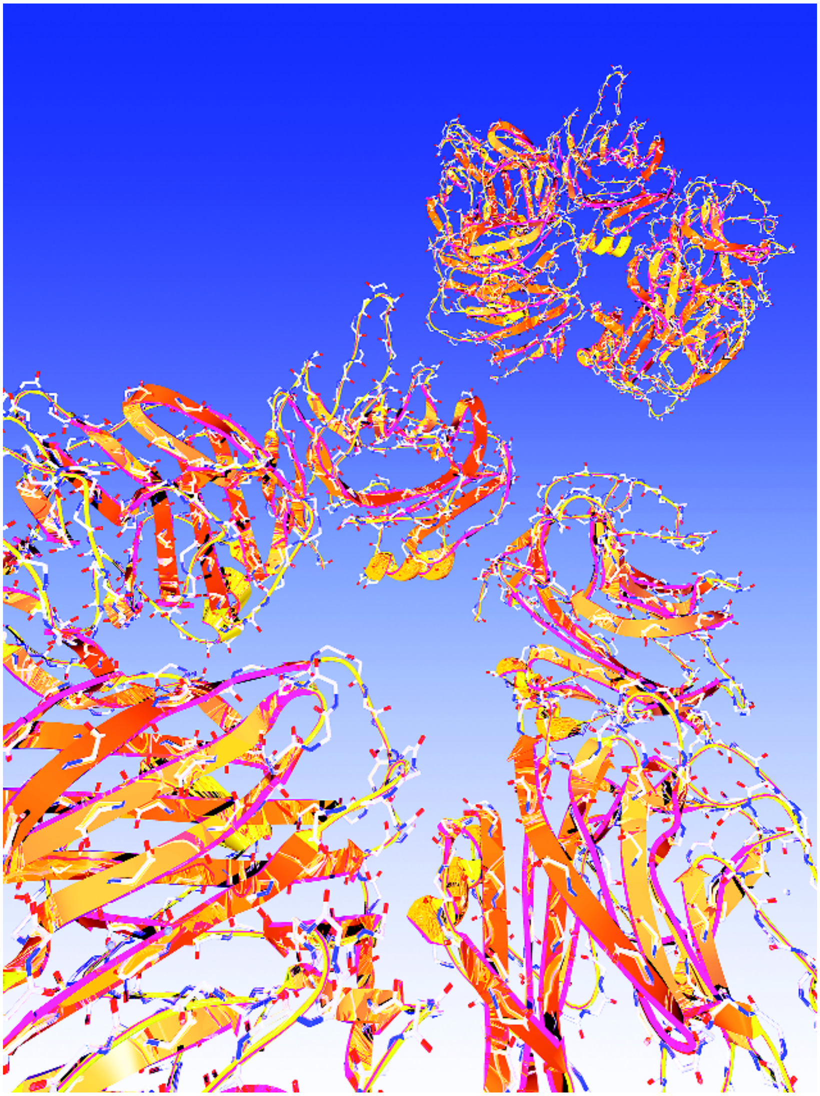
C-reactive protein is a large, complex molecule (cluster of atoms). It is made by the human body as part of its inflammation response. Inflammation is the redness, heat, swelling, and pain that happen in response to an injury or an infection. A sore throat, the swelling of a bug bite, and the hot feeling of sunburned skin are all signs of inflammation.

Inflammation can happen inside the body for no apparent reason. Low-grade or slight inflammation of the arteries—the blood vessels that take oxygen-rich blood from the lungs to the rest of the body—can contribute to atherosclerosis. Atherosclerosis (ATH-a-row-skla-RO-sis) is the building up of a fatty lining inside the arteries. If the lining gets too thick, blood cannot get past, and tissues downstream from the blockage can die. If the arteries supplying the heart (the coronary arteries) are blocked, the heart can be injured or stopped. This is called a heart attack. If a heart attack affects enough of the heart, the person dies. Blockage of an artery in the brain kills off part of the brain, and may damage a person's mind or kill them if there is enough damage. Blockage of blood flow to part of the brain is called a stroke or brain attack.

People with low-grade inflammation inside their bodies are more likely to have heart attacks or strokes. It is not known what causes low-grade inflammation of this kind. However, in recent years scientists have found that several proteins are increased in the blood of people who have low-grade inflammation. One of these is C-reactive protein.

Scientific Foundations

There is always some C-reactive protein in a person's blood. People who have higher levels than normal, however, are more likely



Computer model of the C-reactive protein structure. *Alfred Pasieka/Photo Researchers, Inc.*

to get diabetes, high blood pressure, heart attacks, and stroke. (Together, high blood pressure, heart attacks, and stroke are called cardiovascular disease.) A person having less than 1 milligram of C-reactive protein per liter of blood (1 mg/L) is at low risk for cardiovascular disease. A person with 1 to 3 mg/L has average risk. If a person has more than 3 mg/L, they have high risk. Smoking, lack of exercise, and being overweight increase C-reactive protein in the blood.

Don't Just Measure, Target

As of 2006, a $20 test for measuring C-reactive protein in the blood was being used by many doctors. In that year, one group of researchers suggested that inflammation actually makes tissue death worse in heart attacks and strokes. Since inflammation depends partly on C-reactive protein, these doctors suggested that chemicals that inhibited C-reactive protein—that is, which prevented it from working—might reduce the damage from heart attacks and strokes. They showed that this approach did work in mice. Further research must be done before the method is tried in humans.

Development

The name "C-reactive protein" was given to this protein because when it was first discovered in 1930, it was found to react (that is, combine chemically) with the C polysaccharide (pol-ee-SAK-a-ride) of the bacteria *Streptococcus pneumoniae*, the germ that causes strep throat. Some bacteria coat themselves with molecules called polysaccharides to ward off the immune system. Because it reacted with the C polysaccharide, the newly discovered protein was called C-reactive.

Although the link between inflammation and C-reactive protein has been known since 1930, it was not until the early 2000s that measurements of C-reactive protein levels in the blood began to be used as tests of risk for heart attack and stroke. Guidelines for using C-reactive protein testing were issued in January 2003 by the American Heart Association and the U.S. federal government's Centers for Disease Control.

Current Issues

Although much evidence shows that C-reactive protein can be used to predict risk of cardiovascular disease, not all scientists agree. As recently as February 2006, several researchers challenged the claim that C-reactive protein (and other molecular markers of inflammation) play a role in actually making disease happen, or that measuring them enables doctors to predict disease risk any better than other tests.

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Words to Know

Atherosclerosis: Abnormal narrowing of the arteries of the body that generally originates from the buildup of fatty plaque on the artery wall.

C-reactive protein: A protein which is released during inflammation. Used as a measure of risk for heart attack and stroke.

Heart attack: Blockage of an artery bringing blood to part of the heart. May injure or kill part or all of the heart.

Inflammation: A complex series of events associated with injury or disease that, when combined, serve to isolate, dilute, or destroy the agent responsible and the injured tissue.

Polysaccharide: A molecule composed of many glucose subunits arranged in a chain.

Stroke: Blockage of an artery bringing blood to part of the brain. May injure or kill part or all of the brain.

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Cryonics

Description

Cryonics is an experimental method in which a person's body is frozen and stored immediately after death. The practice is done in the hopes that the person can one day be brought back to life when a cure for what caused their death is found.

Cryonics means "freezing of corpse." A corpse is a dead body. The dead body is kept at an extremely low temperature (below –200 degrees Fahrenheit [–129 degrees Celcius]). A body that is frozen in this manner is said to be in cryonic suspension.

Scientific Foundations

Cryonics is based, in part, on scientific reports that show that body cells can remain alive even if they are not actively working. A 1986 journal report found that large animals that were kept at freezing (32 degrees Fahrenheit [0 degrees Celsius]) after having a heart attack could be brought back to life three hours later. People in favor of cryonics point to events where humans have lived after being in icy waters for long periods of time.

Supporters also say that modern-day cryonics procedures can be used to keep the structure of the brain intact. They believe that the survival of body structure, not the ability to function, determines whether a person lives or dies. Many cryonics supporters also think that, in the future, physicians will have new tools that allow them to target and treat the individual molecules that cause disease (this is called nanomedicine).

Development

The idea surrounding cryonics dates back to 1964, when physics teacher Robert Ettinger (1918–) published a book called

Stainless steel casket used by cryonics company Trans Time, Inc., which uses liquid nitrogen to freeze people shortly after death and then store them at very low temperatures. © *Michael Macor/San Francisco Chronicle/Corbis.*

The Prospect of Immortality. Ettinger proposed that a human body could be frozen and later brought back to life when medical technology was more sophisticated. He also noted that liquid nitrogen could be used to store bodies for hundreds of years. Three years later on January 12, 1967, seventy-three-year-old James Bedford became the first person to be frozen using the cryonics method. Bedford chose the procedure with the dream that scientists would one day find a cure for the cancer that killed him. As of 2006, his body was said to be in good condition at a cryonics facility in Scottsdale, Arizona.

Cryonics companies began to open all over the United States. The expensive cost of storing a frozen body caused many to go out of business within a few years. Only a few full-service cryonics facilities are still open. In 2004, the Alcor Life Extension Foundation said it had more than fifty-nine bodies in cryonic suspension.

The first step in the cryonics process is to remove all the water from body cells and replace it with a mix of chemicals that keep

Cryonics in Popular Media

The potential benefits and problems related to cryogenics have often been the topic of movies, books, and television shows. Examples include:

- The 1992 film, *Forever Young* starring Mel Gibson
- The 1997 film, *Austin Powers: International Man of Mystery* starring Mike Myers
- The 1998 national bestseller, *The First Immortal*, by James Halperin published in 1998
- Television episodes of shows such as *Star Trek: The Next Generation* and *Boston Legal*.

the body from forming ice crystals during freezing. (The water is removed because water expands when frozen. This would cause body parts to break.) The body is then put on ice until it cools down to –202 degrees Fahrenheit (–130 degrees Celsius). The final step is the placement of the body into a metal tank that contains very cold liquid nitrogen.

Among the most famous people ever frozen is American baseball player Ted Williams (1918–2002). Williams's son and daughter had his body frozen at a cryonics facility. Their half-sister sued them for doing this. She insisted that Williams wanted to be cremated instead. The lawsuit was eventually dropped. Williams' body remains in a cryonics facility in the United States.

Current issues

Cryonics is controversial. There is currently no way to reverse the cryonics process so that a person comes back to life. No human adult has ever been brought back to life after deep freezing. Those against the practice say cryonics companies make a promise on which they cannot deliver. Cryonicists (those who support cryonics) disagree. They believe that by the mid twenty-first century, reliable methods to reverse the freezing process and heal any freeze-damaged cells will be developed.

Keeping a body stored in a cryonics center can cost hundreds of thousands of dollars. Before the person dies, they usually must join a cryonics center and pay a yearly membership fee. Many critics say cryonics organizations are robbing people out of a lot of money.

The other debate involves the term "dead." Bodies that are frozen using cryonics are said to be legally but not totally dead,

Words to Know

Cryonicists: Scientists who study cryonics, the science of storing or preserving organisms (or parts of organisms) at very low temperatures.

Cryonic suspension: Storing or preserving organisms (or parts of organisms) at very low temperatures.

and biologically alive. Cryonicists want to perform the freezing process immediately after a person dies, so that all the cells of the body remain technically alive. But the law states that cryonics can only be done on a person who has been pronounced legally dead by an authorized health care provider. The heart must stop in order to be considered legally dead. By the time the body arrives at a cryonics center, many hours may have passed, and cells stop working. This reduces the chance that a person who is frozen can be successfully brought back to life.

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[*See Also* **Vol. 1, Bioethics; Vol. 2, Biopreservation.**]

Cystic Fibrosis Drugs

Description

Cystic fibrosis is a hereditary disease that affects primarily the lungs, sweat glands, digestive system. It is caused by defects in a gene involved in mucus (phlegm) production in the lungs and intestinal tract. (A gene tells cells how to do a particular job.) The disease is most common in Caucasians. Up to 10 percent of Caucasians—millions of people in the United States alone—possess this defective gene. Over 1,000 known mutations of the gene cause mild to life-threatening forms of cystic fibrosis.

In cystic fibrosis, the defective gene results in the accumulation of mucus that is much thicker and stickier than is normally the case. In the lungs, the mucus makes breathing more difficult, and it becomes an ideal location for the growth of bacteria, particularly *Pseudomonas aeruginosa*. When a person with cystic fibrosis gets a bacterial infection in the lungs, it can persist for years because the bacteria are difficult to kill once they are buried in the mucus. As the body's immune system tries to fight the infection, the progressive immune-related damage to the lungs can ultimately be lethal.

In the digestive system, the pancreas secretes enzymes into the stomach that the body needs to digest food. Enzymes are chemicals that make possible the hundreds of chemical reactions that happen every day in the body. When a person has cystic fibrosis, the mucus that the pancreas makes is very thick. It blocks the openings in the pancreas, and the enzymes cannot get to the stomach. As a result, food is not digested as it passes through the stomach.

While no cure exists for cystic fibrosis, a number of drugs are commonly used to try to reduce the number of lung infections, as

Woman receiving treatment with Alpha 1, a drug for cystic fibrosis produced from transgenic sheep. © *Karen Kasmauski/Corbis.*

well as improve the person's quality of life. The wide variety of mutations responsible for cystic fibrosis produces a many different of symptoms. Thus, the drug regimen for cystic fibrosis patients is tailored to the individual.

Scientific Foundations

Cystic fibrosis is a genetic disease, meaning that those who suffer from the disease have inherited a genetic defect from their parents' DNA (deoxyribonucleic acid, their genetic material). Cystic fibrosis is an autosomal recessive disease. This means if two parents both carry the defective gene, their child has a one-in-four chance of developing cystic fibrosis. The parents do not have to have the disease themselves; they are called carriers. They can carry the faulty gene without being sick.

As the genetics of cystic fibrosis were unraveled, the nature and mechanics of the disease have become clearer. This has allowed the drugs to be prescribed that more effectively treat the disease. Cystic fibrosis drugs are aimed at reducing lung infections, making breathing more comfortable, and ensuring that nutrition is adequate.

A Viral Cure for Cystic Fibrosis?

Adenoviruses are small infectious agents that can cause upper respiratory and other infections in humans. They also are known to be a good vehicle for transporting genes inside cells, including, hopefully, the defective lung cells of people with cystic fibrosis. Using an adenovirus, a properly functioning gene could be introduced into these lung cells, and the patient's cells then would be able to produce a properly functioning channel protein. A trial of this treatment with cystic fibrosis patients has shown encouraging improved lung function.

Development

Antibiotics (drugs that fight infections caused by bacteria) can be very useful in treating the lung infections associated with cystic fibrosis. Generally, the first antibiotic prescribed is a drug that has been in use for some time. The idea is that if this antibiotic doesn't work, then more potent antibiotics remain to be tried. Antibiotic therapy is not always successful, since the bacteria are embedded in both the thick mucus and in a sugary substance that they produce after they attach to the lung cells. These embedded bacterial populations, which are called biofilms, are very resistant to drug treatment.

Bacteria can also develop a resistance to antibiotics, since the drug may not be able to penetrate the mucus in a concentration that is high enough to kill all the bacteria. Those bacteria that survive exposure to the antibiotic may change in ways that allow them to resist that antibiotic if it is prescribed again. For this reason, the antibiotics given to a person with cystic fibrosis may need to be shifted over time.

Other cystic fibrosis drugs target the reduced breathing capacity of the mucus-clogged lungs. The airways to the lungs can become constricted. The inhalation of drugs that are classed as bronchodilators (brong-ko-die-LATE-urs) can help increase the amount of air that enters the lungs by causing the small air passages in the lungs to expand. Another treatment supplies an enzyme called dornase. This enzyme recognizes and cleaves sites in the mucus, which makes the mucus thinner. The thinner mucus can be coughed up more easily, providing some short-term comfort and, when combined with antibiotic therapy, increasing the effectiveness of the antibiotics. Drugs that increase the volume of the mucus are also useful, since they effectively reduce its thickness.

Words to Know

Antibiotic: A compound produced by a microorganism that kills other microorganisms or retards their growth. Genes for antibiotic resistance are used as markers to indicate that successful gene transfer has occurred.

Bronchodilators: Drugs, either inhaled or taken orally, that dilate lung airway by relaxing the chest muscles.

Cystic fibrosis: A fatal disease in which a single defective gene prevents the body from making a protein, cystic fibrosis transmembrane conductance regulator.

Enzyme: A protein that helps control the rate or speed of chemical reactions in the cell.

RNA: Ribonucleic acid. Used by most cells to copy protein recipes from DNA; in retroviruses, RNA is the primary genetic material.

Inhalation of corticosteroids (kor-ti-ko-STAIR-oids) and nonsteroidal anti-inflammatory drugs, such as ibuprofen, can slow the lung damage associated with cystic fibrosis, probably because they reduce the inflammation associated with the immune response such as inflammation. Much of the lung damage that occurs in cystic fibrosis is due to the reaction of immune complexes with the lung tissue.

Finally, treatment directed at proper nutrition includes providing pancreatic enzymes, which replace enzymes that are abnormal or missing completely. In addition, people with cystic fibrosis often take dietary supplements, including vitamins A, D, E, and K.

Current Issues

Researchers continue to develop and test drugs that slow the course of cystic fibrosis and its associated lung damage. Research is also being done to find ways of preventing the disease or reversing its effects.

RNA interference may be a promising strategy. RNA is short for ribonucleic acid. RNA interference blocks the process of translation—when an RNA species is used as a blueprint for the manufacture of a protein. Scientists have successfully restored the function of the defective channel in cystic fibrosis lung cells by blocking the activity of a particular protein. While the research is a long way from being ready to use in patients, scientists hope that RNA interference may someday cure cystic fibrosis.

For now, the knowledge of the genetic causes of cystic fibrosis is being used to better identify those people who carry one of these defective genes. In the United States, this service—called genetic screening or genetic testing—is offered to couples who have a family history of the disease and to other prospective parents who wish to be tested.

■ ■ ■

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[*See Also* **Vol. 2, Genetic Engineering; Vol. 1, Vaccines.**]

Designer Genes

Description

Genes are the traits children inherit from their parents. Genes give a child his mother's eyes, or her father's dimples. Genes are segments of DNA (deoxyribonucleic acid, an organism's heriditary material). Genes contain instructions for the production of chemicals called proteins that direct the functions of the different cells in the body. Through the new technology of genetic engineering, it is theoretically possible to manipulate the genes of humans in a way that people can choose what kind of characteristics they would want a child to have. Genetic materials that are manipulated in this way are sometimes called designer genes.

Scientific Foundations

Scientists already use genetic engineering techniques to place another organism's DNA into a plant or animal, in order to achieve a number of desired traits. This is done to make agricultural crops stronger and more disease-resistant. Scientists also can genetically alter animals to make them bigger and to give their meat more nutrients for people to eat.

The next step is changing human genes. Doctors can use genes to select some traits a child will have. They can test an embryo in the lab to make sure it does not have a genetic mutation (a damaged or missing gene). Genetic mutations cause diseases such as Tay Sachs (a disease that causes a fatty substance to build up in nerve cells of the brain) and cystic fibrosis (a disease that causes a sticky substance to form in the lungs, making it hard for the person to breathe). By choosing an embryo without these mutations, doctors can make sure the baby will not have the genetic disease. Genetic diseases such as Tay Sachs are determined by just one gene. Scientists may soon be able to test to see whether a person might develop diseases such as heart disease or cancer. These diseases are determined by several genes.

Doctors can choose the sex of the baby by looking at the embryo's chromosomes (structures in the cells that carry the genes). If they implant an embryo in the mother with the XX chromosomes, the baby will be a girl. If they implant an embryo with the XY chromosomes, the baby will be a boy.

The next step is to actually change or add genes in the embryo so that the child has certain traits. There are two ways to change human genes. The first is used in people who have a faulty gene that causes them to have a genetic disease such as cystic fibrosis. Doctors inject the person with the correct gene, which is usually carried into the person's body on a virus. The idea is that the normal gene will replace the person's faulty gene.

The other way to create designer genes is to remove a cell from a fertilized embryo. Scientists add, remove, or change some of the genes in that cell. They put the genetically modified cell into a woman's egg that has had its nucleus (the part of the cell that contains DNA) removed. If the embryo grows into a child, the changed genes tell the child's body to produce certain proteins that affect a certain trait. That child develops the traits that those genes determine, and pass those traits on to his or her children.

Development

In 1953, American researcher James Watson and British researcher Francis Crick announced that they had "found the secret of life." The pair of scientists had identified the structure of DNA, the container of all hereditary information needed to make human beings. In the 1960s, scientists identified the codes for all the major amino acids, the building blocks of the proteins that tell the human body how to work.

The first time scientists were able to make a "test-tube" baby in a lab was in 1978. Doctors took an egg from the baby's mother and merged it with sperm from the father in a lab, then re-implanted it into the mother to grow. This is called in-vitro fertilization.

In 2001, the first genetically engineered babies were born. The fifteen mothers who participated had genetic defects that they might have passed to their babies. A fertility clinic in New Jersey took an egg from each of the women, combined it with their partner's sperm, and added part of an egg donated by another woman to prevent the babies from having the defect. At least two of the babies who were born had genes from all three parents.

Designer Baby Saves Sibling

In 2000, a Colorado couple created a test-tube baby to save the life of their six-year-old daughter, Molly, who had a bone marrow disease called Fanconi anemia. Molly needed a bone marrow transplant (a treatment in which she would receive new cells to replace her damaged bone marrow cells) in order to survive. Her parents used a procedure that tests the mother's egg and the father's sperm in a laboratory to make sure they did not contain the gene for Fanconi anemia. Scientists then combined the best egg and sperm to create an embryo that contained the exact kind of cells Molly needed for her transplant.

When Molly's baby brother, Adam, was born, doctors collected cells from his umbilical cord to use in the transplant. These cells, called stem cells, were able to successfully make healthy new bone marrow cells that saved Molly's life.

A major breakthrough for designer genes came in 2003. In that year, researchers at the Human Genome Project announced they had sequenced the entire 20,000–25,000 genes in human DNA. They discovered the instructions for making a human being. Their discovery helps scientists find and change genes in an embryo to prevent disease or create certain traits.

Current Issues

Designer genes have the potential to one day prevent health problems such as cancer and blindness, or change the way people look or act. Some people think the practice is morally wrong. They do not believe parents should have the right to engineer their child to be as tall as a basketball star, or as brilliant as Albert Einstein. They picture a world in which parents can mix and match a child, choosing everything from their eye color to their abilities. They fear rich people will be able to buy themselves the best and brightest children.

Many people are afraid designer genes could lead to the practice of eugenics—creating only perfect children to improve the human race. Or, they worry that the practice will create superhuman people with bizarre traits. They imagine people strong enough to lift cars, or people with vision sharp enough to see in the dark. Even more worrisome to some is that these new designer genes could be passed down from generation to generation.

Words to Know

Chromosome: A thread-shaped structure that carries genetic information in cells.

Cystic fibrosis: A fatal disease in which a single defective gene prevents the body from making a protein, cystic fibrosis transmembrane conductance regulator.

Deoxyribonucleic acid (DNA): The double-helix shaped molecule that serves as the carrier of genetic information for humans and most organisms.

Embryo: An organism (human being, other animals, and plants) in its earliest stage of development.

Eugenics: A social movement in which the population of a society, country, or the world is to be improved by controlling the passing on of hereditary information through selective breeding.

Genes: Pieces of DNA that carry instructions for traits and diseases.

Genetic mutation: A change in the genes caused by a change in the base sequence.

Nucleus: The part of the cell that contains most of its genetic material, including chromosomes and DNA.

Protein: Complex molecules that cells use to form most of the structures and control chemical reactions within a cell.

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[*See Also* **Vol. 1, Bioethics; Vol. 1, Frozen Egg Technology; Vol. 1, Gene Therapy; Vol. 1, In-Vitro Fertilization.**]

Dialysis

Description

In many animals, as the blood circulates, it collects waste products from the body's cells. Normally, these wastes are filtered from the blood by a pair of organs called the kidneys. The kidneys pass the wastes on in fluid called urine, which then leaves the body. Kidneys can become damaged from disease or injury and stop working. When a person's kidneys fail, partly or completely, there are only two ways to keep that person from dying. The first is a kidney transplant. In a kidney transplant, a kidney is taken from the body of a living person (a volunteer) or from a person who has died recently. Kidney transplants can only work if the body chemistry of the donor (the person from whom the kidney is coming) is similar enough to the body chemistry of the recipient (the person getting the kidney). There is a long waiting list for kidneys, and most people with kidney failure cannot count on getting a transplant.

The second treatment is dialysis (pronounced die-AL-ah-sis, from the Greek word for "separation"). Dialysis is the artificial removal of waste chemicals from the blood. In order to stay alive, a person without working kidneys must undergo dialysis every few days. There are two kinds of dialysis, hemodialysis and peritoneal dialysis.

The prefix "hemo-" means blood, so hemodialysis means "separation of the blood." In hemodialysis, wastes are separated from the blood using a machine. Three times a week, dialysis patients must spent three to five hours hooked up to a hemodialysis machine. Blood leaves the body slowly through a needle and tube, is filtered by the dialyzer machine using a thin membrane, and is returned to the body through another needle.

Woman receiving hemodialysis treatment on a cruise ship. © *Jeff Greenberg/Visuals Unlimited.*

Another kind of dialysis is peritoneal dialysis. The peritoneum is a thin sack of tissue that contains most of the organs of the gut, including the liver and intestines. In peritoneal dialysis, a tube is used to fill this sack with a cleaning fluid called dialysis solution. The fluid enters through a permanent opening in the side of the body. The peritoneum acts like the membrane in a mechanical dialyzer, allowing poisons to move from the blood into the fluid. After thirty minutes or so, the fluid is drained.

Scientific Foundations

In hemodialysis, separation of wastes takes place in a device called a dialyzer or artificial kidney. The dialyzer makes blood flow on one side of thin membrane or sheet of material and a solution of salt and water on the other side. The membrane is semipermeable (pronounced SEM-ee-PUR-mee-ah-bul), meaning that some molecules (clusters of atoms) can pass through it and others cannot. A semipermeable membrane can be thought of as being punctured by millions of tiny holes that are large enough to let smaller molecules pass but not large molecules or blood cells.

Livers, Too

For over 40 years dialysis has been regularly used to replace the function of the kidneys. However, the kidney is not the only organ that removes toxins from the blood; the liver does, too. While kidneys (and artificial kidneys) remove poisons that can be dissolved in water, livers perform a more difficult trick: they remove substances that are chemically bound to a blood protein called albumin. It is more difficult to imitate this function mechanically than to imitate the filtering action of a kidney. Today there are several kinds of liver dialysis machines, but their stage of development is about where the kidney dialysis machine was in the 1950s, before the invention of the Scribner Shunt: liver dialysis can help keep people with liver failure alive until an organ is available for transplant, but it cannot keep a person alive indefinitely.

Waste molecules are free to pass back and forth through the membrane. Since there are fewer waste molecules on the water side of the semipermeable membrane, more molecules will pass, on average, from the blood side to the water side. A few of these will pass back again into the blood, but they are outnumbered by molecules passing from the blood to the water. This process of movement from high concentration (in this case, the blood side) to low concentration (the water side) is called diffusion. A dialyzer removes waste products from the blood by diffusion.

Development

Early dialysis machines were not good enough to keep people alive who had no kidney function. The first dialyzer or artificial kidney was built in 1943 by a Dutch doctor, Willem Kolff (1911–). Kolff moved to the United States in the late 1940s and continued his research. In the 1950s, he produced improved models.

In 1963, Dr. Belding Scribner (1921–2003) had the idea of feeding blood from a patient's artery through a dialyzer through Teflon plastic tubes, then back into the patient through a vein, in a continuous loop. This invention, the Scribner Shunt, made it possible to perform modern dialysis. In 1962, Scribner opened the world's first dialysis clinic, where people living otherwise ordinary lives would come regularly to have their blood cleansed.

Peritoneal dialysis first became a practical treatment for kidney failure in the 1980s.

Words to Know

Dialysis: The mechanical filtering of blood to replace the functioning of kidneys or liver.

Diffusion: Random movement of molecules which leads to a net movement of molecules from a region of high concentration to a region of low concentration.

Hemodialysis: A method of mechanically cleansing the blood outside of the body, used when an individual is in relative or complete kidney failure, in order to remove various substances which would normally be cleared by the kidneys.

Peritoneal dialysis: An alternative to hemodialysis in cases of kidney failure. Instead of pumping blood out of the body, dialysis fluid is drained into and out of the abdomen to absorb toxins.

Current Issues

Dialysis is not a perfect replacement for a natural kidney. There are several medical problems that often trouble people who are depending on dialysis. These include weakening of the bones, which afflicts 90 percent of all dialysis patients; itching; inability to sleep; and amyloidosis, which is pain in the joints caused by the buildup of proteins that living kidneys can remove but dialyzers cannot.

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For More Information

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[*See Also* **Vol. 1, Organ Transplants.**]

DNA Fingerprinting

Description

Deoxyribonucleic acid (DNA) is the genetic material inside every cell in the human body. It is made up of pairs of the chemicals adenine (A), cytosine (C), guanine (G), and thymine (T). The combinations of these base pairs form a code that gives instructions to the body's cells. Every person's code is a bit different (except for identical twins). By looking for unique pieces of this code, scientists can identify a person by a strand of their hair, a drop of their blood, or other piece of their body tissue.

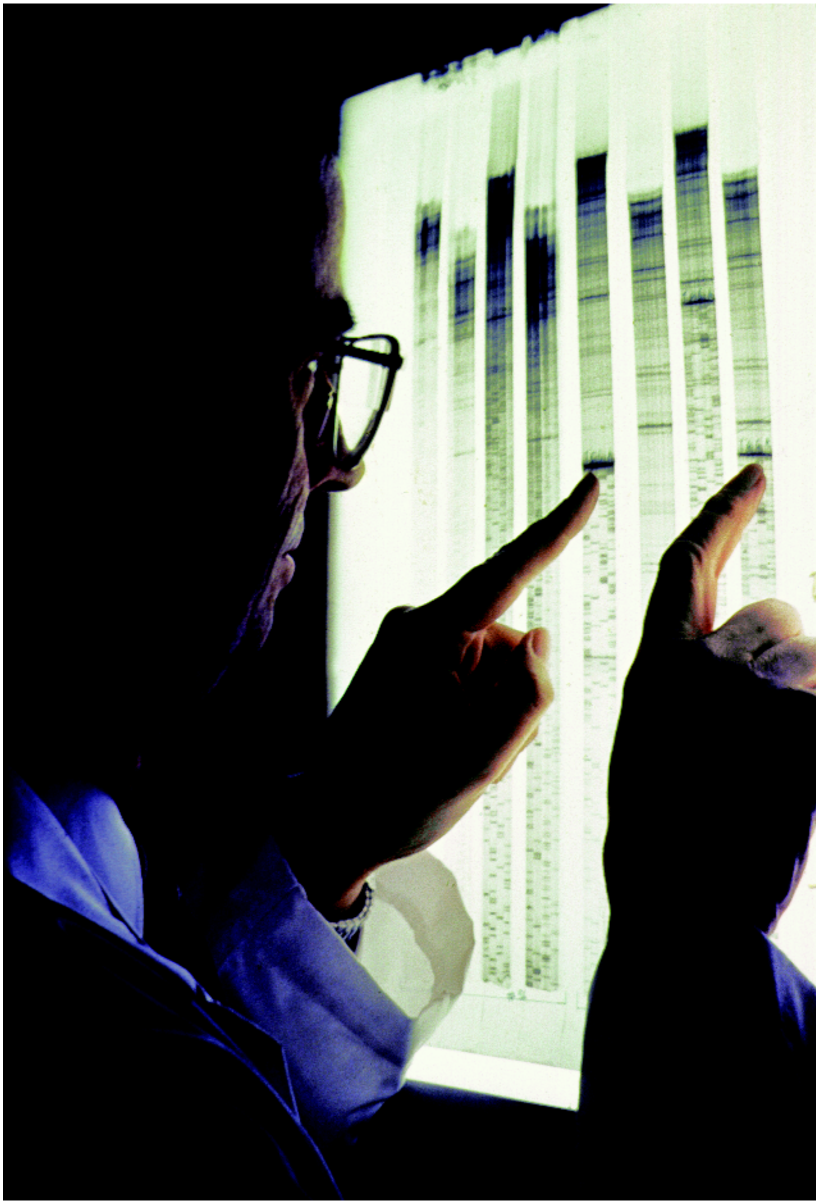
Fingerprints left at a crime scene have long been used by police investigators to find out whether a certain person committed the crime. DNA fingerprints can be used for the same purpose. The difference is, regular fingerprints can only be found on the tips of a person's fingers. DNA fingerprints are in every cell and tissue in the body.

DNA fingerprinting can also be used for other purposes. It can help find out if a newborn baby has an inherited disease, determine who a child's father is (paternity testing), and it can help identify a body found at an accident scene.

Scientific foundations

Picking out matching pieces of DNA is not easy, since each human being has about three billion DNA base pairs. About ninty-nine percent of a person's DNA is exactly the same as everyone else's DNA. But one percent of DNA (about three million base pairs) is unique to each person. Scientists look for those specific areas of unique DNA when trying to match a sample to a person.

To make a DNA fingerprint, scientists pull DNA from a tissue sample. The sample may be a drop of blood, a hair, or a piece of

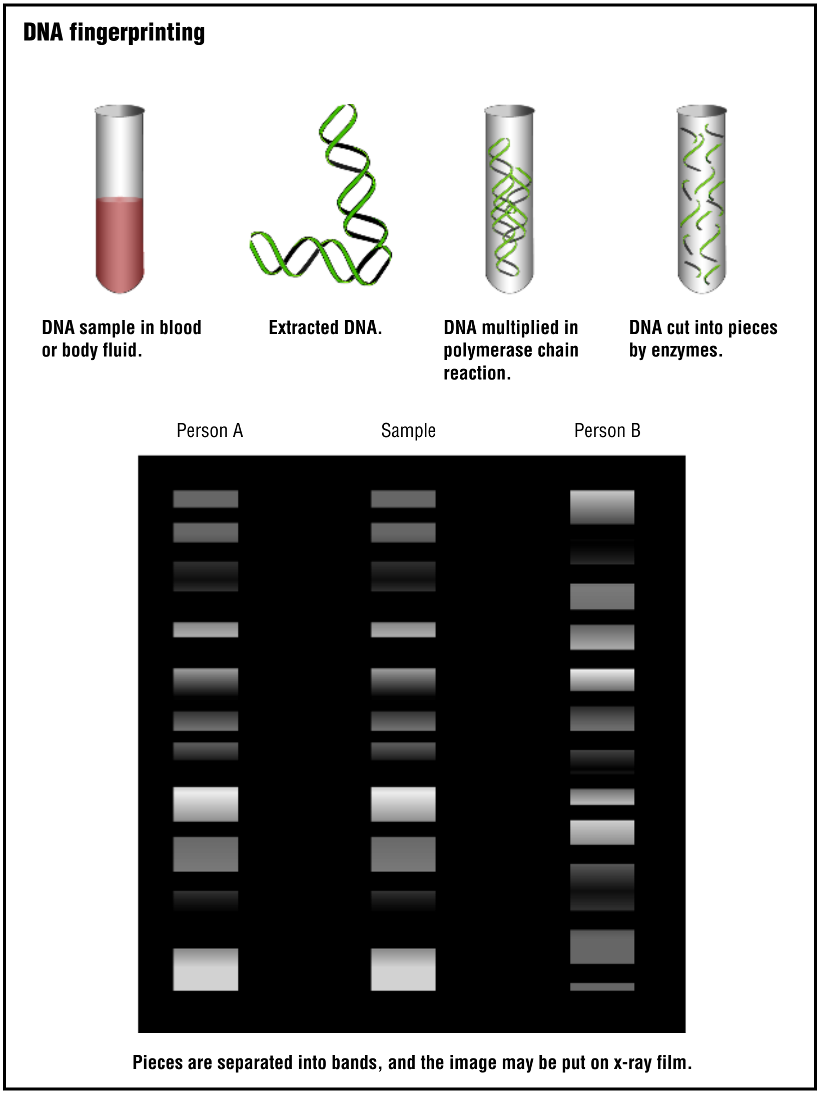


Researcher comparing two DNA fingerprints to determine the identity of a criminal. © *Visuals Unlimited.*

skin found at the scene of a crime. They also take a DNA sample from a person who is a suspect in the crime. Then they remove the DNA from the nucleus of the cell.

An older method for DNA fingerprinting is called restriction length fragment polymorphism (RFLP). Scientists break the DNA into pieces using a special enzyme (a protein in the body that

To compare DNA fingerprints, a DNA sample is obtained from, in this case, two people, A and B. Once the DNA is analyzed and put on x ray film, it can be compared to a sample DNA fingerprint, for example, taken from a crime scene to make a match. *Illustration by GGS Inc.*


DNA fingerprinting
DNA sample in blood or body fluid.
Extracted DNA.
DNA multiplied in polymerase chain reaction.
DNA cut into pieces by enzymes.
Person A
Sample
Person B
Pieces are separated into bands, and the image may be put on x-ray film.

triggers chemical reactions). The enzyme cuts the DNA at certain sequences of bases. Each type of enzyme looks for a certain sequence to cut (for example, one enzyme might look for the pattern, GAATTC). The cut segments of DNA are separated using a special gel. Then the DNA is moved from the gel onto a type of nylon film. Radioactive (giving off high-energy rays) strands of DNA, called probes, are placed on the film. The probes only stick to certain parts of the DNA. This produces a picture pattern when seen with an x-ray machine (which uses high-energy rays to make a picture). The pattern is the person's DNA fingerprint. It looks a

Wrongly Accused

DNA not only can find someone who is guilty of a crime, it also can free a person who was falsely accused of a crime. In 1992, Guy Paul Marin of Canada was convicted of the murder of a nine-year-old girl and was put in jail. When he was convicted, DNA testing was still a new science. A few years later, it had improved. A test of Marin's DNA in 1995 showed that he had not committed the murder. He was cleared of the crime. In 1997, DNA testing also helped to free a man named Kenneth Adams from prison. He had spent eighteen years in jail for a murder that he did not commit.

lot like a supermarket bar code. Scientists compare the DNA pattern with that of a sample that they know comes from the suspect. If the DNA samples match in a few places, chances are they are from the same person.

Although RFLP is good at finding DNA matches, it can only be used when scientists have a lot of DNA from a person. A newer method, called polymerase chain reaction (PCR), works with much smaller DNA samples. It uses small sequences (about one to four base pairs) of DNA. These small sequences are sometimes called short tandem repeats (STRs). They repeat over and over again. PCR uses special enzymes to make more of the DNA sequences. When they have made enough DNA, scientists can find STRs that are unique to the person.

In the future, scientists may not have to wait to get back to the laboratory to get a DNA fingerprint. A new method called lab-on-a-chip is a small computer that would analyze DNA samples right at a crime scene.

Development

Genetic fingerprinting was invented in the early 1980s by a scientist named Alec Jeffreys at Leicester University in England. Professor Jeffreys and his assistants had been studying DNA to see how it differed from one person to another. They were trying to learn how to track hereditary diseases through families. Professor Jeffreys was using x-ray film to look at the DNA. When he pulled the film out of the developing tank, he noticed patterns in the DNA. He realized that he could use these patterns to identify people.

The first criminal was caught using DNA fingerprinting in 1987. Two years later, the method was used to help free a man who was

Words to Know

Deoxyribonucleic acid (DNA): The double-helix shaped molecule that serves as the carrier of genetic information for humans and most organisms.

Enzyme: A protein that helps control the rate or speed of chemical reactions in the cell.

Paternity: The genetic father of an offspring.

Polymerase chain reaction (PCR): Polymerase chain reaction. A method of making many copies of a short piece of DNA quickly.

Radioactive: The production of high-energy rays as a result of changes in the atomic structure of matter.

Restriction length fragment polymorphism (RFLP): A variation in the DNA sequence, identifiable by restriction enzymes.

X ray: Electromagnetic radiation of very short wavelength, and very high energy.

previously convicted of rape. The courts today look at thousands of DNA fingerprints in criminal cases.

Current issues

DNA fingerprinting is the most accurate method for identifying people to date. But because it is done by hand, there can be mistakes. For example, a hat found at a crime scene may have been worn by more than one person, so it would contain more than one person's DNA. There is a small chance that someone who is linked to a crime by DNA fingerprinting could be innocent.

To help them solve crimes, the Federal Bureau of Investigation (FBI) keeps a computer record of DNA fingerprints. It contains more than one million profiles on people and samples from crime scenes. Some people fear that this database threatens people's privacy. They think the government might be able to learn everything about a person's health from his or her DNA fingerprint and keep it in its database.

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[*See Also* **Vol. 1, DNA Sequencing; Vol. 3, Fingerprint Technology; Vol. 1, Forensic DNA Testing.**]

DNA Sequencing

Description

DNA (deoxyribonucleic acid) is the molecule used by almost all living things to control the chemistry of life and to pass on traits to offspring. Messages are coded into DNA as strings of small chemical building blocks called bases. The bases act like letters in written language. Much like finding out how words are spelled by examining the order of letters composing the word, DNA sequencing is the process of finding out the order (sequence) of the bases in a DNA molecule.

Creatures of the same species have similar DNA sequences, but there are still differences between individuals. DNA differences are part of what makes people different in color, height, health, and other traits that can been seen and measured.

DNA sequencing is done using special laboratory equipment that combines DNA with other chemicals to identify a few bases at a time. Several methods for DNA sequencing have been invented.

DNA is basic to all living things, so knowledge of DNA sequences can be used in many ways. DNA sequences are useful in tracing how different species have evolved (changed over time). They are also useful in creating new medical treatments. As with most technologies, however, DNA sequencing could also be used in harmful ways. For example, people whose DNA is thought to have defects might be discriminated against.

Scientific Foundations

The DNA molecule is shaped like a ladder with millions of rungs. Each rung of the ladder is made of two chemicals called bases that lock together form a pair. There are four types of bases,

Researchers analyzing a DNA sequence. *Custom Medical Stock Photo. Reproduced by permission.*

usually abbreviated as A, G, C, and T (the first letters of the DNA bases adenine, guanine, cytosine, and thymine), that can make up the base-pair rungs of the DNA ladder. The sequence of As, Cs, Ts, and Gs running up the ladder is what DNA sequencing determines.

Each DNA molecule twists along its length like a licorice stick to form a double spiral or double helix. The double helix is then crumpled and mixed with other molecules to form a bundle called a chromosome. Chromosomes are too small to see without a powerful microscope. Apart from red blood cells, which lose their DNA, every cell in the human body contains 46 chromosomes (22 chromosome pairs and two special sex chromosomes designated as X and Y chromosomes). Females carry two X chromosomes. Males carry an X and a Y chromosome. Chromosomes are separate DNA molecules. There are about three billion base pairs in the human chromosomes in each cell.

Development

A Swiss biologist named Johann Miescher discovered the DNA molecule in the late 1800s. In 1929, Russian-American scientist

Phoebus Levine discovered that DNA contained the A, C, G, and T bases. In the 1940s, scientists began to understood that DNA is the genetic material, that is, the substance that carries the information that allows information (and traits such as eye color) to pass from parent to child. The discovery that it has a twisted-ladder or double-helix shape was finally made in 1953 by English Physicist Francis Crick and American Molecular Biologist James Watson.

The genetic code was discovered in the late 1950s. The genetic code is the way in which sequences of A, C, G, and T bases specify the structures of the large molecules called proteins, which carry out most of the body's chemical tasks. Each series of bases that specifies a protein is called a gene. The average gene is 3,000 bases long, but some genes are over two million bases long. There are about 30,000 genes in the human genome (complete set of human DNA) and about 100,000 different proteins in the human body.

To understand the genome of any species, the sequence of bases in the DNA of that species must be known. DNA sequencing is the technology that makes this knowledge possible. In 1977, two methods of sequencing DNA were developed. The one that is more widely used is the chain termination method or Sanger method, was invented by Frederick Sanger.

In the Sanger method, DNA is first extracted from a living cell and broken into fragments. Each DNA fragment is mixed with chemicals that make millions of copies of it grow in a lengthwise, base-by-base way. Four such mixtures are made. In one, another chemical causes each DNA copy to stop growing when it ends with an A base. In another, a chemical causes each DNA copy to stop growing when it ends with a C base. Two other mixtures produce DNA copies that end only in Gs and Ts. The growth-stopping chemicals are present in low enough concentrations so that growth is sometimes stopped the first time an A, C, G, or T base is reached, sometimes the second time, and so forth. The result is that fragments of all possible lengths are produced in each mixture.

The next step in the Sanger method uses the fact that longer DNA fragments are larger molecules. Using the method called gel electrophoresis, each of the four types of fragment mixtures—that containing all possible fragments ending in A, that containing all possible fragments ending in C, and likewise for G and T—are made to travel through a strip of gel or jelly that slows down larger molecules more than it slows down small ones. In this way, fragments of different lengths are separated in the gel, just as fast runners move away from slow runners on a race track.

Ninety-Six Percent Monkey

Fast DNA sequencing has recently made it practical to sequence the genomes (all the DNA) of several species of animal. A first draft of the human genome was published in 2001, of the mouse genome in 2002, of the rat genome in 2004, and of the chimpanzee genome in 2005. A final sequence for the human genome was released in 2003.

We can now compare the DNA of chimpanzees and of humans in detail. It turns out that 96 percent of chimp and human DNA is the same. Scientists have long known that chimpanzees are our closest evolutionary cousins—the two species are descended from a single ancestor species that lived about six million years ago—but by comparing DNA base by base and gene by gene, they can now begin to track exactly what it is that makes us genetically human.

All the DNA fragments ending in A are separated in one gel strip, all the sequence fragments ending in C are separated in another, and likewise for G and T. Four gel strips are produced. Each strip shows a series of spaced-out dark bands. Each band is a place where DNA fragments of a particular length have separated from all others.

If the gel strips with four bands are laid side by side, the base sequence of the original DNA can finally be read. For example, if the first dark band on any of the four strips is in the A strip, then the first base in the DNA being sequenced is an A. If the second dark band is on the C strip, then the second base is a C—and so on to the end of the sequence.

Originally, all the steps of the Sanger method had to be done by hand. In the 1990s, the process was automated so that it could be controlled by computer. This made DNA sequencing much faster. By 2003, the entire human genome had been sequenced.

Current Issues

Everyone's DNA is a little different from everyone else's. Most of these differences are harmless, but about 4,000 are known to cause diseases. DNA sequencing allows a patient's genes to be tested for disease-causing genes. If a disease-causing gene is present, doctors can watch for the beginnings of that disease, and if discovered, begin treatment early. On the other hand, this information could be also used against the patient. For instance, insurance companies might refuse to give health insurance to people who carry genes that might cause certain diseases (even if the chances are small that they will develop a particular disease), or employers might refuse to hire them.

Words to Know

Base: One of the four chemical letters in the DNA code. There are four kinds, called A, C, G, and T (short for adenine, cytosine, guanine, and thymine).

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

DNA sequencing: A method of finding out the sequence of base pairs in a DNA molecule.

Gel electrophoresis: A laboratory test that separates molecules based on their size, shape, or electrical charge.

DNA sequencing is used in police work to match suspects with DNA left at crime scenes. A number of people imprisoned for crimes have been proven innocent and released because their DNA did not match DNA from crime scenes.

Another use for DNA sequencing is the prevention of drug reactions. Over 100,000 people die in the United States every year after taking certain medicines. The difference between the people who are helped by a drug and the people who are hurt is thought to be in their DNA. Scientists are trying to discover which DNA differences make which medicines risky. If a patient's DNA is sequenced, then it may be possible to identify which drugs they should not take.

DNA sequencing is also allowing scientists to trace the evolutionary family tree of life in greater detail than ever before. The theory of evolution has been confirmed by the huge amount of new information supplied by DNA sequencing.

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[*See Also* **Vol. 1, DNA Fingerprinting; Vol. 1, Gene Therapy; Vol. 1, Genetic Discrimination; Vol. 1, Genetic Testing, Medical; Vol. 1, Genomics.**]

DNA Vaccines

Description

Vaccines are substances made of dead or weakened germs (such as viruses or bacteria) that help protect people against diseases. Effective vaccines change the immune system (the body's natural defense system against foreign chemicals and organisms) so it acts as if it has already developed a disease. The vaccine prepares the immune system and its antibodies (disease-fighting substances) to react quickly and effectively when threatened by the same disease in the future.

A DNA vaccine is a bit different from a regular vaccine. Instead of using the whole virus (or other disease-causing organism) to trigger an immune response, it uses just a few genes (pieces of DNA that carry instructions for traits and diseases) from that virus. The DNA provides information, or codes, that tells cells how to make proteins (substances that carry out different functions of the cells). The genes in the DNA vaccines teach the vaccinated person's immune system to respond to the virus when it sees it. It is able to protect the body against further attacks because the protein lives a long time.

Development

The first vaccine was created by British physician Edward Jenner (1749–1823) in 1789. It protected against a dangerous illness called smallpox by using the related, less-dangerous cowpox virus to build up immunity. Jenner also coined the word "vaccination" to refer to this treatment. Since then, scientists have made vaccines for polio, mumps, whooping cough, and many other serious diseases.

For two hundred years, regular vaccines were the main methods for preventing diseases. However, in 1993, researchers at Merck

Rows of DNA synthesizers, automatic and high speed machines used to make short sequences of customized DNA (DNA with specific base sequences), are used to make the artifical DNA used in some DNA vaccines. *AP Images.*

Research Laboratories in Pennsylvania made a major discovery. They injected just the genes for a flu virus protein into mouse muscles. The mouse muscle cells began producing the virus protein. That protein caused an immune response that protected the mouse from the flu. This was the beginning of DNA vaccines.

In 2005, the first DNA vaccines were approved for animals. One vaccine protects salmon from a dangerous virus. The other protects horses from the West Nile virus (a disease that can cause swelling of the brain and spinal cord). No DNA vaccines have yet been approved for human use.

At first, when DNA vaccines were experimentally given to people, they did not work well because the genes were not able to get into the human cells. In later tests, human DNA vaccines were more effective. Scientists are testing DNA vaccines for diseases such as acquired immune deficiency syndrome (AIDS—a disease that damages the immune system), cancer, smallpox, and the flu. DNA vaccines might also be used to protect against cancer, allergies, and other health problems. As of mid-2006, DNA vaccines for human use are still under development, but progress is being made toward their approval worldwide.

Research into a DNA Vaccine for HIV

As of 2006, there was no vaccine to prevent infection by the human immunodeficiency virus (HIV), the virus that causes AIDS. It is important to develop an effective and safe vaccine, since over 25 million people died from AIDS-related causes between 1981 and 2005. Consequently, scientists around the world are working intensively to develop a DNA vaccine and have tested many of these vaccines. Such vaccines are made artificially, so they do not contain any actual HIV viruses. As a result, DNA vaccines cannot infect anyone with HIV. So far, the only side effects associated with experimental HIV DNA vaccines have been minor irritation around the injection area, a low fever, and minor body aches that quickly go away. As with other experimental DNA vaccines, a future HIV vaccine should be safe, inexpensive to make, and not need refrigeration, so that it will be easy to store and give to those who need it.

Scientific Foundations

DNA vaccines are made of gold particles. The particles are coated with a small, circular piece of DNA. The particles are injected into a person's cells, usually within a muscle because muscle cells are more receptive. The vaccine then delivers the DNA into the cells.

The vaccine's DNA contains genes that code for a certain protein, called an antigen. This protein causes an immune response, just like a regular vaccine. The vaccine teaches the person's immune system to fight off the target disease.

In the future, there may be other ways to deliver a DNA vaccine. A nasal spray is one possible method. The spray would carry the vaccine into the person's lungs, where the genes would be taken into lung cells.

Current Issues

DNA vaccines have several advantages over regular vaccines:

- With a regular vaccine, the vaccine itself causes an immune response in the person who is vaccinated. As a result, the effects of regular vaccines can sometimes wear off. Some vaccines have to be given more than once to protect a person. Since DNA vaccines generate the immune response with genes functioning inside a person's own cells, they can protect a person from a disease for a lifetime.

Words to Know

Acquired immune deficiency syndrome (AIDS): An epidemic disease caused by an infection with the human immunodeficiency virus (HIV).

Antigen: A molecule, usually a protein, that the body identifies as foreign and toward which it directs an immune response.

Antibody: A molecule created by the immune system in response to the presence of an antigen (a foreign substance or particle). It marks foreign microorganisms in the body for destruction by other immune cells.

Bacteria: Microscopic organisms whose activities range from the development of disease to fermentation.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Immune system: A system in the human body that fights off foreign substances, cells, and tissues in an effort to protect a person from disease.

Mutation: A change in a gene's DNA. Whether a mutation is harmful is determined by the effect on the product for which the gene codes.

Pathogen: A disease causing agent, such as a bacteria, virus, fungus, etc.

Polio: A disease (poliomyelitis) caused by a virus that can result in muscle weakness, paralysis, or death.

Protein: Complex molecules that cells use to form most of the structures and control chemical reactions within a cell.

Smallpox: A deadly viral disease that was eradicated in the 1970s. Today the virus only exists in closely-guarded samples held by the American and Russian governments.

Virus: A very simple microorganism, much smaller than bacteria, that enters and multiples within cells. Viruses often exchange or transfer their genetic material (DNA or RNA) to cells and can cause diseases such as chickenpox, hepatitis, measles, and mumps.

Whooping cough: An acute infectious disease caused by *Bordetella pertussis* that causes spasms of coughing and convulsions.

- Many regular vaccines contain live, but weakened, versions of the pathogen (disease-causing organism). Some people can get sick, if their immune systems are not strong enough to fight off even the weaker version of the pathogen. DNA vaccines only contain the certain genes from the pathogen, not the whole organism. As a result, they cannot make a person sick. This makes the DNA vaccine useful for diseases such as AIDS, which are too dangerous to use as a regular vaccine.
- Regular vaccines must be given one shot at a time. To get all of his or her vaccinations, a child might have to visit the doctor many times. But, a single shot of a DNA vaccine could protect against more than one disease.

- Regular vaccines are very expensive and difficult to make. Most are grown inside chicken eggs. Making just a one-year supply of the flu vaccine, for example, takes millions of chicken eggs. It also can take more than six months to produce the vaccine. This means scientists cannot make a regular flu vaccine quickly if needed. DNA vaccines can be made much more rapidly using machines that make custom DNA (DNA with specific base sequences). This makes DNA vaccines both less expensive and faster to produce than regular vaccines.
- Regular vaccines must be kept cold, which makes them hard to carry from place to place. In addition, scientists must make new batches every year because they do not store well. DNA vaccines can be stored at many different temperatures. And they can be kept for many years without going bad.

There are some concerns about DNA vaccines. One of the biggest concerns is that the DNA from the pathogen might get into a person's genes. This could possibly cause a permanent change to the genes, called a mutation. Although tests with DNA vaccines are promising, they still have not proven effective in protecting humans.

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[*See Also* **Vol. 1, Genomics; Vol. 2, Recombinant DNA technology; Vol. 1, Vaccines.**]

Enzyme Replacement Therapy

Description

An enzyme is a chemical that plays an important role in the chemical reactions that take place inside an organism. Essentially, all the functions of the cells in our bodies are chemical reactions, and many different enzymes are essential to ensure that our cells are working properly. Enzymes are types of proteins, which are the primary components of living cells.

Enzymes are vital for many functions in the body. When an enzyme malfunctions or does not function at all, diseases can development. Examples of diseases caused by missing or malfunctioning enzymes include cystic fibrosis, Fabry disease, and Gaucher disease.

Enzyme replacement therapy is a treatment that replaces a specific nonfunctioning enzyme with a functional version of the protein. Alternately, this therapy can supply the body with a gene that will ultimately produce a functional version of the particular enzyme. A gene is a piece of DNA, or genetic material, that tells a cell how to produce a particular protein. If the correctly functioning gene is supplied through enzyme replacement therapy, it will tell a cell how to produce the enzyme needed. If the defective enzyme has caused a disease, then enzyme replacement therapy can reverse these effects. Enzyme replacement therapy is a new, experimental treatment for some diseases.

Scientific Foundations

Cystic fibrosis, Fabry disease, and Gaucher disease are all genetic disorders. This means that those who suffer from these diseases have inherited a genetic defect from one or both of their parents. Since genes tell cells how to make proteins, including

Family affected by Pompe's disease, a genetic disorder for which enzyme replacement therapy is being tested. The girl and boy in front have the condition. © *Najalh Feanny/Corbis.*

enzymes, having a faulty or missing gene (a mutation) can result in cells that do not make enough, or any, of a particular enzyme. The result can be a genetic disorder. Not all people with the same genetic disorder have the same symptoms. Sometimes there are many different mutations for a single gene, and which mutation a person has determines the type and severity of symptoms.

Replacing an absent or malfunctioning enzyme can be done by directly supplying the enzyme as a part of medical treatment for a disease. Alternately, the gene encoding the enzyme can be supplied. If the gene is successfully incorporated into the hosts' genetic material, then the inserted gene can direct cells to produce the appropriate enzyme. Enzymes may be isolated from human or animal blood or tissues, or they may be genetically engineered. Genetically engineered enzymes often cause fewer bad reactions in patients, and they can be produced in much larger quantities than can be obtained from natural sources.

Another Cost of Enzyme Replacement Therapy

Enzyme replacement therapies for relatively rare maladies, such as Gaucher disease and Fabry disease, are expensive on a per-patient basis. In countries where medical care is largely provided through tax revenues, the resources for health care are limited and must be allotted. This creates a dilemma. The allocation of funds to very expensive treatments for relatively few people could result in less money to treat diseases that affect more people. As populations age and the need for medical care increases, the debate about the accessibility to publicly funded medical care will continue to grow in urgency.

Development

One disease that can be successfully treated using enzyme replacement therapy is Gaucher disease. In this disease, there is not enough of an enzyme called glucocerebrosidase (GLOO-koh-sair-a-BROH-sa-days). This causes the accumulation of a compound called glucocerebroside (GLOO-koh-SAIR-a-broh-side) in cells. As a consequence, the compound accumulates in the liver and spleen (both organs filter blood), which become enlarged. Various organs stop working properly, and the skeletal system deteriorates.

By regularly receiving doses of a glucocerebrosidase-containing medication, these symptoms can be reversed in people who have Gaucher disease. Because the enzyme is supplied directly, the medication must throughout the person's life for the beneficial effects to be maintained.

Another disease that is treated with enzyme replacement therapy is Fabry disease. In Fabry disease, an enzyme called alpha-galactosidase (al-fa-ga-LAK-toe-sa-days) is missing, and its absence causes fats to build up in blood vessels over time. The reduced efficiency of blood flow causes the kidneys and heart to malfunction or even to stop functioning. While rare, Fabry disease is a serious health concern. The treatment of Fabry disease consists of regular infusions of an enzyme, in this case a genetically engineered form of alpha-galactosidase.

People with cystic fibrosis have mucus (phlegm) that is thicker and stickier than normal. In addition to breathing problems, patients can experience difficulty in digesting food, due to mucus that clogs the digestive system. The mucus also inhibits digestive enzymes from being able to break down food in the stomach and intestines. In the past, those with cystic fibrosis often needed to

Words to Know

Enzyme: A protein that helps control the rate or speed of chemical reactions in the cell.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Protein: Complex molecules that cells use to form most of the structures and control chemical reactions within a cell.

Vector: A vehicle used to deliver foreign genes into another organism's DNA. Viruses are the most commonly used vectors.

adopt a different diet to compensate for this enzyme deficiency. By giving people with cystic fibrosis the enzymes that are normally produced by the pancreas, their intestinal levels of these enzymes are raised, which enables food to be digested more efficiently. For patients on enzyme replacement therapy, a normal diet is possible.

Current Issues

Despite its successes, enzyme replacement therapy is still in its infancy. Ensuring that an enzyme reaches its target and that its activity is maintained is not easy. But, with experience, the number of diseases that respond positively to the addition of a critical enzyme(s) will surely grow.

Research into gene-mediated enzyme replacement will continue, as will other types of gene therapy. If it can work well, gene-mediated enzyme replacement is a better treatment for some diseases, since it would eliminate the need to periodically supply patients with the preformed enzyme. Once a gene is inserted into a host's genetic material, the beneficial enzyme could produced by that person's body indefinitely.

Getting the gene into the body is a challenge as well. Other types of gene therapy use viruses as vectors. This means that the beneficial gene is put inside the virus, which is then injected into the body. The virus then delivers the gene to cells. The most common viral vectors are adenoviruses, which are the same kind of viruses that cause colds.

In the laboratory, gene delivery has been achieved using liposomes (LIP-a-sohmes). Liposomes are artificially created hollow spheres whose outer wall is constructed of lipid (fat) molecules. The beneficial is injected into the liposome, which is delivered into the body.

More efficiency enzyme replacement therapies also will reduce the cost of the therapy, which is currently very expensive.

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[*See Also* **Vol. 1, Cystic Fibrosis Drugs; Vol. 1, Designer Genes.**]

Forensic DNA Testing

Description

Deoxyribonucleic acid (DNA) is the material that contains a person's genetic information. DNA testing is used to analyze and compare DNA from two or more people. Sometimes, members of law enforcement perform DNA testing—what they sometimes call DNA profiling—on people who are victims or suspects in crimes. Police officials use DNA from blood, hair, skin, and other materials found at crime scenes to find out who is (or is not) responsible for crimes. When DNA testing is performed to solve crimes, it is called forensic DNA testing.

Forensic scientists check about thirteen different DNA regions that have been found to vary from person to person. Information is collected in a DNA profile (sometimes called a DNA fingerprint) that identifies an individual. By using these different DNA regions, scientists can decide whether two people have the same or different DNA profile.

After a person's DNA profile is determined, law-enforcement officers use computers to record the information digitally. In this way, they can use the DNA information in the future and share it with other police around the world. The courts in the United States accept forensic DNA information as evidence in paternity suits and generally accept it in criminal trials.

Scientific Foundations

DNA is a molecule that looks like a ladder that has been twisted into the shape of a winding staircase—what scientists call a double helix (HEE-liks). The rungs of this chemical ladder are small molecules or building-blocks that spell out a chemical message like a long line of letters. Cells read the DNA code like a book of

Researchers using forensic testing to identify a human rights abuse victim in Guatemala. © *Karen Kasmauski/Corbis.*

recipes, putting together many different molecules that the cell needs to live. All living organisms that contain cells have DNA. In mammals, such as humans, pieces of DNA are grouped into chromosomes, which are located in the nucleus of each cell. DNA also is the molecule used by all living cells to pass traits on to the next generation. For example, if a child has red hair, then either her mother or father (or both) passed that trait to the daughter before she was born.

Development

American biologist James Watson (1928–), English biologist Francis Crick (1916–2004), and New Zealander-English biophysicist Maurice Wilkins (1916–2004) shared the Nobel Prize in physiology or medicine in 1962 for discovering the structure of DNA. In 1985, English geneticist Sir Alec Jeffreys (1950–), while doing research at the University of Leicester, invented DNA testing. Soon after, this technique was used to solve crimes (what is called forensics). In fact, Jeffreys' technique was first used to

Super Bowl and Olympic Souvenirs

DNA technology is used in many ways, and the number of ways are increasing each year. For example, footballs used in Super Bowl competitions are marked with an invisible, permanent piece of artificial DNA. Balls, caps, jerseys, and other items used in Olympic Games are marked with natural DNA from unidentified athletes. Such sports souvenirs are marked with DNA and tested with specially designed lasers to make sure that people can recognize real souvenirs from those made by dishonest means. Unfortunately, souvenir fraud has become common in sports. By using DNA technology, such fraud can be stopped with the use of forensic DNA testing.

identify a man who murdered two English people in 1983 and 1986. The DNA of the suspect was tested and found to match DNA found at the crime scene. The suspect was later convicted of murder based partially on the DNA evidence.

Jeffreys later improved on his DNA testing technique by identifying a few characteristics (what he called minisatellites) of the DNA. By concentrating on these minisatellites, Jeffreys was able to make DNA testing more accurate. In 1995, the technique developed by Jeffreys was used to establish the National DNA Database (NDNAD) in England.

Current Issues

Only about 0.1 percent of DNA differs from person to person. From that tiny amount of difference, forensic DNA testing can result in a non-match or a match. A non-match proves without a doubt (100 percent) that the two samples came from two different people. However, when two samples are considered identical (a match), there is only a very high likelihood (well over 99.99 percent, but still not quite 100 percent) that the two samples came from the same person. In a criminal case, for example, DNA evidence can show that the odds of an accused person actually committing the crime to be one in one billion. The result does not absolutely mean that the accused person did not commit the crime. However, it does show that it is very likely that the person did not commit the crime. Many people are found guilty or innocent of crimes based on DNA evidence.

The media and members of the legal profession, such as defense lawyers, have questioned the reliability of forensic DNA testing. However, no court has ever rejected DNA evidence based on its

Words to Know

Chromosome: A thread-shaped structure that carries genetic information in cells.

Nucleus: A compartment in the cell which is enclosed by a membrane and which contains its genetic information.

Paternity: The genetic father of an offspring.

unreliability. DNA evidence has only been rejected due to errors in the testing process, such as incorrect readings by laboratory technicians. In fact, laboratory errors have been one of the biggest problems to DNA testing. Human errors are becoming less common as technicians gain more experience in reading DNA samples and as more standard tests are used throughout the world.

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[*See Also* **Vol. 1, DNA Fingerprinting; Vol. 1, DNA Sequencing; Vol. 3, Fingerprint Technology.**]

Frozen Egg Technology

Description

The process of freezing a woman's eggs so that they can be used at a future time is a new technology. Once a woman is ready to have a baby, the eggs can be thawed and fertilized (merging sperm with an egg to form a new human being). Eggs and sperm contain the hereditary material, or DNA (deoxyribonucleic acid), of the parents. DNA is packaged in sections called genes.

In vitro fertilization is a process that combines a woman's egg with a man's sperm in a laboratory to form an embryo (a multicelled fertilized egg). The embryo can then be implanted in the woman's uterus where it continues to develop into a baby. Doctors have been able to freeze embryos for many years. In vitro fertilization often results in too many embryos. The extra embryos may be frozen until the woman is ready to get pregnant, but many stay frozen for years because the parents do not use them. Keeping embryos frozen is controversial because some people believe embryos are human lives. Freezing only the eggs provides another option.

Scientific Foundations

In order to collect eggs from a woman, she is given specific hormones (chemicals in the body that control the actions of cells and organs) that make her ovaries produce more eggs than normal. A doctor then surgically removes the eggs from the woman's ovary using a small needle.

The eggs must be protected during the freezing process so they are not damaged. One way to do this is by adding chemicals to the eggs. The chemicals replace the water in the eggs to prevent ice

Frozen Zoo®

Frozen eggs could also play an important part in preserving endangered animals. The Frozen Zoo, affiliated with the San Diego Zoo, collects and maintains frozen eggs, sperm, embryos, DNA, and tissue samples of animals whose numbers are dwindling in the wild. Scientists hope to ensure the survival of endangered species by learning efficient techniques to assist their reproduction.

crystals from forming when the eggs are frozen. Another method is to freeze them so quickly that ice crystals do not have a chance to form.

When a woman is ready to get pregnant, doctors thaw one or more eggs using special chemicals. The eggs and sperm are combined in a lab. If they make an embryo, the doctor places it in the woman's uterus to grow.

Development

Doctors have been able to freeze and thaw sperm for many years. They have also been able to freeze embryos. But freezing eggs has taken longer because it is hard to do without damaging them.

Eggs contain a lot of water. When a human egg is frozen, ice crystals form. The ice crystals destroy the chromosomes (the structures that contain the genes) in the eggs. Researchers discovered this in the 1980s when they experimented with freezing mouse eggs. Freezing also forms a coating around the egg that is hard for the sperm to swim through.

In 1986, the first baby was born using frozen eggs with the help of a doctor in Australia. A year later, doctors in Germany also achieved pregnancies using frozen eggs. However, it was another ten years before doctors started using frozen eggs regularly.

The first American woman to have a baby using a frozen egg was in 1997. In 2004, doctors in Italy reported that they were able to fertilize 123 frozen eggs. Out of those eggs, thirteen babies were born. By the beginning of the twenty-first century, fewer than two hundred babies had been born using frozen eggs.

Eggs can be frozen for many reasons. It can preserve a woman's eggs until she is ready to have a baby. The older a woman gets, the harder it is for her to get pregnant. With age, the eggs lose quality. When a woman goes through menopause in her forties or fifties, her periods stop and her body no longer releases eggs. A woman

Words to Know

Chromosome: A thread-shaped structure that carries genetic information in cells.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Embryo: An organism (human being, other animals, and plants) in its earliest stage of development.

Genes: Pieces of DNA that carry instructions for traits and diseases.

Hormone: A chemical substance produced by the body. Hormones are created by one organ of the body but they usually carry out functions in other organs or parts of the body.

In-vitro fertilization: Combining an egg and a sperm in the laboratory to create an embryo that is then implanted in the mother's uterus.

Ovaries: Female reproductive organs that contain unfertilized eggs.

Menopause: The time in a woman's life when the chemical environment of her body changes, resulting in decreased estrogen production (among other things) and the cessation of her menstrual period.

Uterus: Organ in female mammals in which the embryo and fetus grow to maturity.

can freeze her eggs when she is young and then use them when she is older if she is having trouble getting pregnant.

Freezing eggs can also help a woman who has cancer have a baby. A treatment for cancer called chemotherapy uses drugs to kill cancer cells. These drugs may damage the ovaries (the female sex glands that produce eggs and hormones). Without working ovaries, a woman cannot produce eggs. If a woman freezes her eggs first, she can use them to get pregnant once her cancer treatment is finished.

Women who are unable to get pregnant with their own eggs can receive donor eggs. Donor eggs can be frozen in order to move them from one city to another.

Even with advances in the science of frozen eggs, success rates remain low. By 2006, only about two out of every one hundred frozen eggs resulted in a live birth. In comparison, in vitro fertilization using non-frozen eggs produced about eight or nine babies per one hundred eggs.

Current Issues

Before they were able to freeze eggs, doctors could freeze embryos. Some people objected to the fact that embryos could remain frozen for years. Many people believe that embryos are still human life, and should not be wasted.

Freezing eggs has less controversy, but there are still issues with the process. One issue is that frozen eggs could allow much older women to have babies. Some people believe women in their fifties, sixties, or seventies are too old to have a baby.

There also may be problems with using eggs that have been frozen. Scientists are still not sure whether freezing could affect the chromosomes in the eggs because the science is relatively new. Changes to the chromosomes could potentially cause the babies to have health problems.

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[*See Also* **Vol. 1, Bioethics; Vol. 1, In-Vitro Fertilization.**]

GenBank

Description

GenBank is a database run by the National Institutes of Health (NIH), part of the U.S. government. A database is a collection of information that can be seen using a computer. The GenBank database contains all stretches of decoded DNA that have been made available to the public. Anyone with a computer can look at the GenBank database for free.

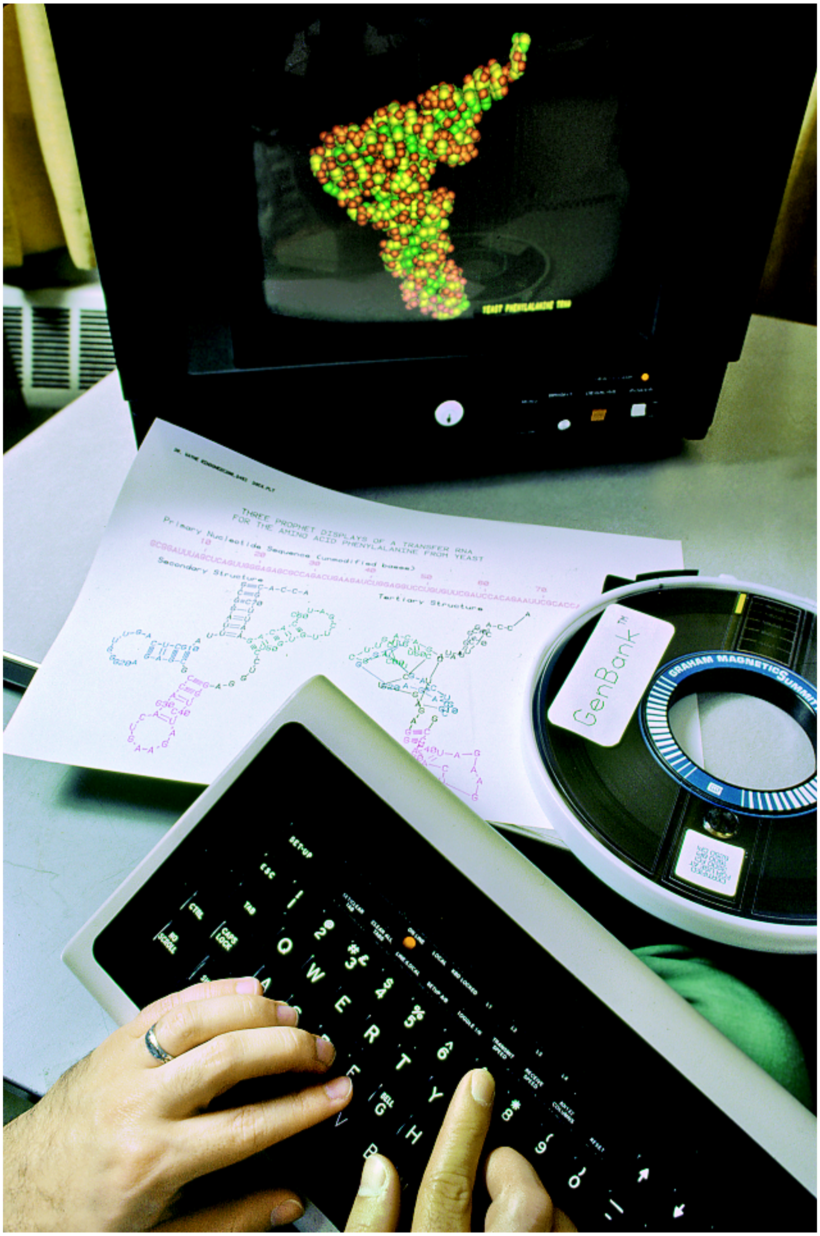
GenBank is used by scientists around in the world in many ways. For example, by examining differences between the DNA of similar species, biologists who study evolution can tell how species are related. They can even tell how long ago species split apart into separate lines of descent.

Despite its name, GenBank is not a gene bank. A gene bank contains actual DNA molecules; GenBank contains only information.

Scientific Foundations

DNA (short for deoxyribonucleic acid) is the molecule that controls heredity and the manufacture of the molecules called proteins in almost all living cells. Heredity is the passing on of traits from one generation to the next.

Each DNA molecule is a long chain of atoms that resembles a twisted ladder having thousands or millions of rungs. Each rung in this chemical ladder is made of two smaller molecules locked together in the middle. Each of these smaller molecules is called a base. There are only four kinds of base in DNA, called adenine, cytosine, guanine, and thymine (A, C, G, and T for short). The order in which these four bases occur along the length of the DNA molecule is like a code. The code gives cells instructions for


THREE PROPHET DISPLAYS OF A TRANSFER RNA
FOR THE AMINO ACID PHENYLALANINE FROM YEAST
Primary Nucleotide Sequence (unmodified bases)
Secondary Structure
Tertiary Structure
GenBank™
GRAHAM MAGNETICS SUMMIT

A computer terminal for GenBank, a computer database of genetic information. © *Ted Spiegel/ Corbis.*

making proteins. Cells live and reproduce by making proteins according to the recipes coded into their DNA.

Most base pairs are grouped together in strings or packages called genes. A gene is a short section of DNA that controls the manufacture of a protein in a living cell or helps control how other

100 Billion Served

GenBank works with two other DNA database projects, the European Molecular Biology Laboratory's European Bioinformatics Institute and the DNA Data Bank of Japan, to keep track of all the DNA sequences known to science. In August 2005, the three projects made a proud joint announcement: together, they had made available to the public information on 100 billion bases (letters of the genetic code). One hundred billion is about the number of nerve cells in the human brain or stars in our galaxy. The public DNA library offered by GenBank and its partners now contains over 55 million sequences from at least 200,000 different organisms. Thanks to these databases, biologists can now study the DNA of entire ecosystems (communities of living things) and study life in other complex ways that were never possible before.

genes are decoded. Genes are passed from parent to offspring in all living things. A single gene often contains thousands of base pairs. The complete set of genes of an organism is called the genome.

Much of the information in GenBank is long lists of base pairs, recorded as the letters A, C, G, and T. GenBank also lists sequence information for RNA, a molecule that is similar to DNA and is also found in almost all living cells.

A sample GenBank file, for a single gene of the common yeast *Saccharomyces cerevisiae*, can be seen online at http://www.ncbi.nlm.nih.gov/Sitemap/samplerecord.html. Part of the record looks like this:

ctaacgaaga atccattgtg tcgtattacg gacgttctca gttgtataat gcgccgttac

Development

In 1980, the NIH sponsored a meeting of scientists to talk about the need for a DNA database or "data bank" as it was then called. Based on advice from the scientists, and working with the National Cancer Institute and other official organizations, the NIH set about setting up the Genetic Sequence Data Bank or GenBank. The information in GenBank first became available to the public on October 1, 1982. Earlier that year the European Molecular Biology Laboratory's European Bioinformatics Institute, had already opened for business, becoming the world's first public DNA database.

At that time the Internet did not exist, and distribution of GenBank information was mostly by means of computer-readable magnetic tapes and a yearly printout in book form. Today, access to GenBank is entirely online. A software package from the National

Words to Know

Base: One of the four chemical letters in the DNA code. There are four kinds, called A, C, G, and T (short for adenine, cytosine, guanine, and thymine).

Base pair: Two bases bonded together—either A with T, or C with G—to bridge the two spirals of a DNA molecule, much as a rung connects the two uprights of a ladder.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Genome: A complete set of the DNA for a species.

Protein: Complex molecules that cells use to form most of the structures and control chemical reactions within a cell.

Center for Biotechnology Information (NCBI) called Entrez allows access to the information in GenBank, along with information on taxonomy (how species are related to each other), protein structure, genome mapping, and more. Scientists add data to GenBank over the Internet using other software supplied by the NCBI.

Current Issues

GenBank has become a necessary tool for many scientists. It is also, thanks to cheap DNA sequencing technologies that had become available starting in the 1990s, growing faster than ever. As of 2003, GenBank contained records of over 33 billion bases in 27 million sequences and was growing at almost a million sequences (lists of DNA bases) a month. In that year alone, more than 40 complete bacterial genomes were added to the database.

The information in GenBank concerns species; it does not contain DNA information about particular people. Therefore, there has been no public controversy about whether the NIH has a right to hold the information it has in GenBank and make that information available to the public. There is nothing personal or private about any of the information in GenBank.

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[*See Also* **Vol. 1, Bioinformatics; Vol. 1, DNA Sequencing; Vol. 1, Gene Banks; Vol. 1, Human Genome Project.**]

Gene Banks

Description

A gene bank is a collection of seeds or of DNA samples. Such collections are called gene banks because they keep either living genes or information about genes safe for later use.

The gene is the basic unit by which characters or traits are passed from parents to offspring. Each gene is a short piece of DNA that tells cells how to make a particular protein or does some other job. Each human's DNA contains about 25,000 genes. Differences between individual plants and animals are partly the result of differences between their genes. If all corn plants, for example, had exactly the same genes, they would be as much alike as human identical twins.

The two types of gene bank—seed banks and DNA banks—have different purposes. A seed bank tries to make sure that varieties of plants are not lost. Having many species and varieties (also called biodiversity) is important in agriculture for several reasons. Some plant varieties, for example, are better than others at fighting off certain diseases or pests. Others may thrive with different kinds of weather. When varieties are lost, food supplies are more easily harmed by one kind of pest or one kind of bad weather.

DNA banks contain samples of DNA, often from human beings. Police forces and governments can identify people by comparing DNA found on crime scenes with DNA in the gene bank. This method can be used to identify criminals or to acquit people falsely accused of crimes. DNA banks can also be used for medical research. Many people have genes that make them more likely to get certain diseases. By studying genes from many

These varieties of corn are maintained at the Maize Genetics Cooperation Stock Center, a seed bank. *Photo courtesy of the Agricultural Research Service, USDA.*

people, scientists can discover how which genes relate to which diseases.

There is also a British gene-bank project called Frozen Ark, which since 2004 has been collecting DNA samples from endangered animal species.

Gene Bank on the Moon

In 2006, a group called Alliance to Rescue Civilization proposed a gene bank on the Moon that would preserve samples of all Earth's useful seeds from nuclear war, asteroid impacts, or other disasters. The plan was supported by Buzz Aldrin, who in 1969 was the second man to walk on the Moon. ''It's a reasonable thing to do with our space technology,'' Aldrin said, ''sending valuable stuff to a reliable off-site location.'' However, seed scientists answer that merely putting seeds in a safe, whether it is on the Moon or not, cannot preserve biodiversity in the long run. There are a few cases of seeds germinating after 100 years, but most seeds start to die after only 40 years in storage. The only way to keep seed varieties going is to keep raising new seeds from old in greenhouses or fields—which would be hard to do on the Moon, especially if the goal were to save all the many thousands of Earth's crop varieties.

Scientific Foundations

Genes are sections of DNA (deoxyribonucleic acid), the molecule that controls heredity and tells cells how to make proteins. Heredity is the passing on of traits from one generation to the next. A protein is a kind of molecule that is found in all living things.

Almost all living cells contain DNA. Each DNA molecule is a long, twisted chain of atoms. Coded along the chain are instructions for making proteins. Cells live and reproduce by making proteins according to the recipes coded into their DNA.

Development

Seed banks or collections have existed for centuries, but long-term, super-dry, refrigerated storage was not possible until the twentieth century. As of 2006 there were about six million seed varieties saved in some 1,470 gene banks around the world.

A number of tissue banks—institutions that save samples of brain, blood, muscle, or the like—have been saving samples of human and animal tissue for many years. The U.S. National Pathology Repository, for example, has been collecting tissue samples since 1917. Since all tissue samples contain DNA, such repositories act as DNA banks even though that was not their original purpose. Special-purpose DNA banks are a more recent invention. The largest DNA bank in the world, the United Kingdom National Criminal Intelligence DNA Database, was set up in 1995. By 2006, the UK government had more

Words to Know

Biodiversity: Literally, ''life diversity'': the number of different kinds of living things. The more different kinds, the greater the biodiversity.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Genetic discrimination: The denial of rights or privileges to people because of the nature of their DNA.

DNA samples than any country, with samples from more than a twentieth of the United Kingdom's population. Some other ambitious DNA banks, such as UK Biobank (founded 2002), had yet to gather any DNA samples as of 2005.

Current Issues

Seeds must be kept super-dry and super-cold to make them last. Even under these conditions, all seeds slowly die in storage. The only solution is to keep creating fresh seeds by raising adult plants from the old ones. This costs money, but many of the seed banks of the world are poor. In 2002, a report from Imperial College in England said that many seed banks in poor countries were losing funding or electric power due to war. Without electricity, seeds cannot be kept dry and cold; without money, staff cannot be hired to grow fresh seed. "Many critical gene bank collections are in a precarious state," said Professor Jeff Waage, head of the college's department of agricultural sciences. "If these collections are allowed to fail, then we will lose the valuable crop diversity they contain forever." At the 2002 World Summit on Sustainable Development, a United Nations-sponsored effort to raise $260 million for the world's seed banks was launched.

Human DNA banks are a different matter. There is no problem, in principle, with keeping DNA intact for hundreds of thousands of years. There is, however, disagreement over what it will be used for. Since 2004, police in England and Wales have been collecting DNA from every person arrested, even if that person later turns out to be innocent of a crime. Some DNA in the UK criminal database has been used for medical research without the permission of the original owners. Also, some people fear that information from

DNA banks might be used for genetic discrimination—treating people with unusual DNA as if they were not as good as other people.

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[*See Also* **Vol. 1, DNA Fingerprinting; Vol. 1, Forensic DNA Testing; Vol. 1, Genetic Discrimination.**]

Gene Therapy

Description

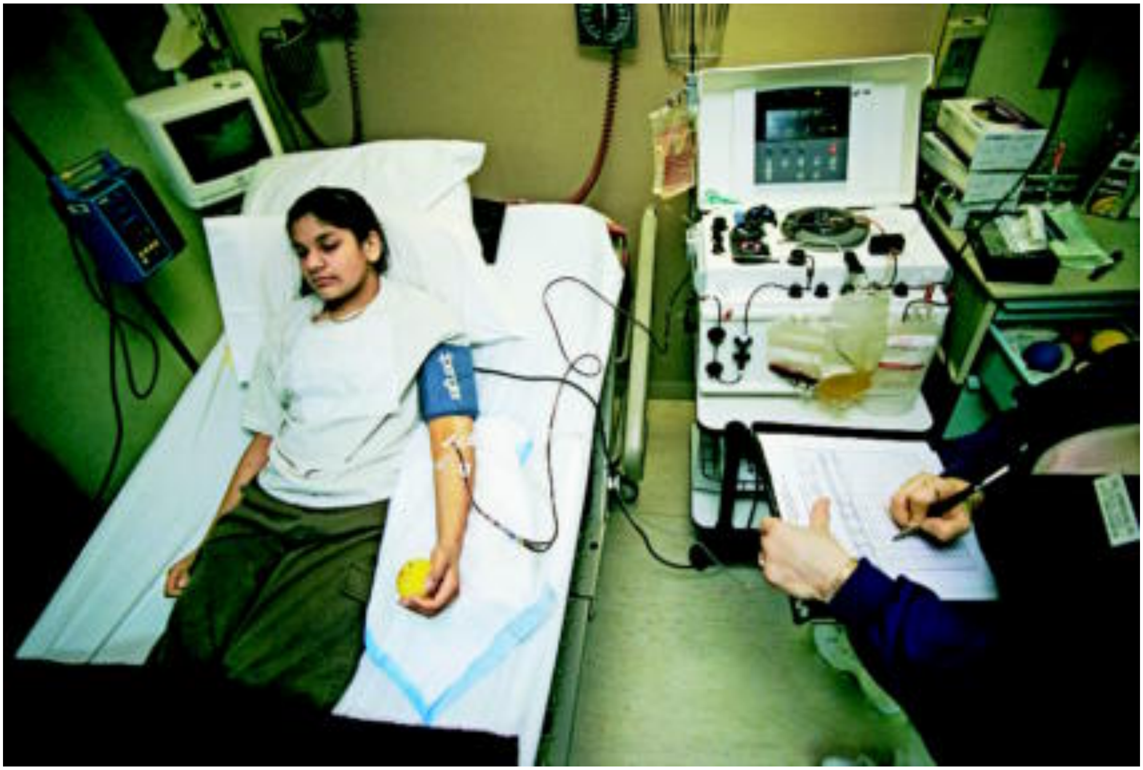
Gene therapy is an experimental medical procedure that attempts to correct a genetic mutation (missing or changed genes) so that properly functioning genes are restored to cells. When gene therapy works, the correct instructions for building proteins (chemicals that direct and control chemical reactions in the body) are once again available to cells, and the body returns to normal or healthier function.

Scientific Foundations

Genes hold the instructions that direct both the form and function of the human body. In humans, genes are small areas in a molecule of deoxyribonucleic acid (DNA). Each gene directs the making of a protein. Proteins are present in every living thing and regulate almost all the functions in the human body. Genetic mutations can be inherited from one or both parents, or they may arise on their own, through a mistake in the reproductive process.

Genes that are mutated can send the wrong instructions to the parts of the cell that build proteins, causing the proteins that are produced to not function properly, or causing the protein to not be made at all. The result can be a disease called a genetic disorder. Because genes also control reproduction and are passed from parents to children, genetic disorders can be passed from parent to child.

There are two basic types of gene therapy, somatic therapy and germline therapy. Somatic cell gene therapy affects only non–reproductive cells. The new genes cannot be passed on to future generations. Germline gene therapy affects reproductive cells (egg



Ashanti de Silva at age thirteen. She was the first patient to receive gene therapy when she first started treatments at age four for an immune system disorder. © *Karen Kasmauski/Corbis.*

and sperm cells) so the new genes can be passed on to future generations.

The way scientists usually deliver genes into the patient's cells is by using a virus as a vector (carrier). Viruses normally carry colds and other diseases into human cells. The viruses used in gene therapy are changed to deliver normal DNA into the cell. The normal genes can then begin making the correct proteins.

Researchers are also working on a way to deliver new genes by inserting an extra, artificial chromosome into cells. Normally, humans have forty–six chromosomes (twenty–three pairs). The additional, forty–seventh chromosome would carry the new genes.

Development

Scientists first began discussing the possibility of gene therapy in the 1960s. In 1970, American doctor Stanfield Rogers at Oak Ridge National Laboratory in Tennessee tried to use gene therapy to treat two sisters who had a genetic disorder called argininemia. With this genetic disorder, the body lacks an enzyme (a type of protein) called arginase. People with this disorder can have seizures and

Retroviruses Rejected for Gene Therapy

In 2000, French researcher Alain Fischer was able to cure children of a similar kind of immune system disorder. Fischer used retroviruses as gene carriers. Retroviruses are a type of virus that uses ribonucleic acid (RNA) as its genetic material, instead of DNA. Retroviruses produce an enzyme (a protein that controls a biochemical reaction) that builds DNA upon a strand of RNA (the opposite of what normally happens in humans where RNA is made on sections of DNA). The most well known of these retroviruses is the human immunodeficiency virus (HIV), the virus responsible for acquired immune deficiency syndrome (AIDS). Fischer inserted a retrovirus carrying the normal gene into the children's blood stem cells. Several months later, two of the children in the trial developed a disease similar to leukemia (a type of cancer that starts in the cells that make blood cells). As a result, the U.S. Food and Drug Administration (FDA) halted all gene therapy that used retroviruses in the United States.

mental impairment. Rogers tried to treat the sisters by using a virus to carry the healthy gene into their cells. In this case, the gene therapy was unsuccessful.

In 1977, scientists were able to use gene therapy techniques to deliver a gene into the cells of mammals. American doctor W. French Anderson performed one of the first studies of gene therapy in humans in 1990 on a four–year–old girl who had a rare genetic immune system disorder called severe combined immunodeficiency (SCID). The immune system fights off infections from bacteria and viruses, and the disorder made it difficult for her body to stay healthy. Anderson and his team genetically altered her white blood cells and then returned them to her body. The new white blood cells strengthened the girl's immune system and made it possible for her to survive.

Another setback to gene therapy occurred in 1999. An eighteen–year–old patient named Jesse Gelsinger was involved in a gene therapy trial for a genetic disease called ornithine transcarboxylase deficiency (OTCD). This rare disease prevents the liver from breaking down ammonia, which can build up in the body and become toxic. Gelsinger died from organ failure four days after starting treatment. Researchers believe his immune system reacted to the virus that carried the new gene into his cells.

Although gene therapy research moved slowly, it still moved forward. In 2003, the first officially licensed gene therapy was

Words to Know

Deoxyribonucleic acid (DNA): The double-helix shaped molecule that serves as the carrier of genetic information for humans and most organisms.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Gene therapy: Treating disease by replacing nonfunctional genes or supplying genes that do function properly.

Genetic disorder: An inherited disorder.

Germline gene therapy: The introduction of genes into reproductive cells or embryos to correct inherited genetic defects that can cause disease.

Leukemia: A cancer of the blood-producing cells in bone marrow.

Reproductive cells: Specialized cells capable of fusion in the sexual cycle; female gametes are termed egg cells; male gametes may be zoospores or sperm cells.

Retrovirus: A virus whose genetic material is RNA (ribonucleic acid), not DNA.

Somatic cell gene therapy: The introduction of genes into tissue or cells to treat a genetic related disease in an individual.

Vector: A vehicle used to deliver foreign genes into another organism's DNA. Viruses are the most commonly used vectors.

available in China. Several types of gene therapy are waiting for approval from the U.S. Food and Drug Administration.

Current Issues

The FDA has to approve all new drugs and therapies before they can be used by the public. As of early 2006, the FDA had not approved any gene therapy technique.

Although there have been a few successes, gene therapy is generally considered experimental. Scientists must overcome a few problems before the therapy can be used by patients. First, the effects of gene therapy often do not last because cells are always dividing. As cells with mutations divide, they keep making more and more faulty genes. Patients must receive some gene therapies many times in order to make sure enough of the new genes reach the targeted cells to make the right proteins.

Second, the immune system recognizes anything that enters the body as foreign. When it sees the viruses that carry the new genes, it tends to attack them. Patients may also have a reaction to the carrier virus itself. Finally, many of the biggest diseases that affect humans (such as cancer and heart disease) are caused by more than one faulty gene. Trying to fix all of those genes simultaneously is a difficult challenge.

Some controversy also surrounds gene therapies. Scientists are concerned that germline gene therapy could have unknown consequences on future generations. Some religious groups argue that altering genes is unethical, even if the goal is curing disease. Others argue that the technique is still too risky.

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[*See Also* **Vol. 1, Somatic Cell Therapy; Vol. 1, Germline Gene Therapy; Vol. 1, Protein Therapies.**]

Genetic Testing, Medical

Description

Genetic testing is when doctors look at a person's DNA (genetic information) to see if they or their children are likely to have medical problems in the future.

Carrier identification. Some diseases, called genetic diseases, are passed by their parents to their children. In some cases the parents may not have the disease themselves: a person must have two copies of a defective gene (DNA segment) to get the disease, and often a person has one copy. The person with one copy is called a carrier. If both parents have the defective gene, however, then the chances are high that at least some of their children will get two copies and therefore have the disease.

Prenatal diagnosis. This is when DNA taken from a developing fetus is tested, usually to see if there is mental retardation or some other severe birth defect. Parents sometimes choose abortion if the test shows that their developing fetus is likely to be born with severe mental retardation.

Newborn screening. Newborn screening is when newborn babies are tested to see if they have genetic disorders that can be better treated if treatment starts at once. Newborn screening can test for dozens of disorders, many involving the body's ability to produce certain substances that are vital to life. If caught early, sickness and death can sometimes be prevented.

Late-onset disorders. Genetic tests are also available for diseases that affect people later in life, such as heart disease, colon cancer, certain kinds of breast cancer, and some other cancers. These tests do not prove that a person is going to have a certain disease, but a positive result means that the person is more likely than other people to get that disease.

Lab technician performing genetic tests. The tests are done three times on the same sample to minimize the chance of errors. © *Hulton/ Archive.*

Scientific Foundations

All living things, whether single-celled or made of billions of cells, use DNA (deoxyribonucleic acid) to pass on traits to their offspring. They also use DNA like a book of recipes for making all the complex molecules (clusters of atoms) called "proteins" that they need to produce during their lifetime. Since almost everybody has slightly different DNA, their bodies make slightly different proteins. This affects how they react to various drugs and foods, and whether they are more or less likely to develop certain diseases, including cancer. (What people eats, how they live, and what chemicals and radiation they are exposed to also affects their health.) In some cases, genes contain errors that can cause serious

Genetic Horoscopes

In the early 2000s, genetic testing went commercial. A number of companies offer predictive genetic testing online. Send them a sample of your DNA and they will analyze it for genetic risks, for a price. Under the heading of ‘‘nutrigenetic’’ testing, they will even tell you what you should eat in order to stay healthy, based on your particular genes. In 2006, the General Accounting Office, which investigates issues on behalf of the U.S. Congress, announced that it had posed as a customer for four genetic testing companies. It had posed as fourteen different customers, in fact, but had sent the companies DNA from only two people. The results should have been similar or identical when the same DNA was used, but were wildly various. Some of the tests—though not all—were, in the words of one government official, no more meaningful than ‘‘genetic horoscopes.’’

birth defects in children. In genetic testing, DNA is isolated from cells, and parts of the DNA are analyzed using DNA sequencing machines. Sequencing is reading the order of the chemical codewords in the DNA molecule.

Development

Before doctors could test for genes that might give trouble, they had to understand what genes are and how they work. This knowledge was gained starting in the early 1950s, when the nature of the DNA molecule was first understood. By the late 1980s, devices existed that allow doctors to sequence DNA cheaply and quickly enough to make genetic testing possible. The popularity and usefulness of genetic testing grew during the 1990s. Today it is a common procedure.

Current Issues

Scientists are beginning to understand the way that genetic differences between persons affect the way that their bodies handle drugs. Some people do better with smaller doses of certain drugs and other people with larger doses, depending, ultimately, on what exact proteins their DNA tells their cells to make. For example, one Caucasion (white) person in about 3,500 makes a version of a protein that breaks down the muscle-relaxing drug suxamethonium chloride. Because these people make a protein that does not break down the drug very well, they recover much more slowly from the drug. Testing somebody’s DNA to see how they should be medicated is called pharmacogenetics. The prefix “pharma-” means

Words to Know

DNA sequencing: A method of finding out the sequence of base pairs in a DNA molecule.

Paternity testing: Genetic testing to determine the father of an offspring.

Pharmacogenetics: The study of how a person's genetic makeup affects his or her response to medications.

Protein: Complex molecules that cells use to form most of the structures and control chemical reactions within a cell.

"drugs"; genetics is the study of genes. However, there are many drugs and many genes, and a person's reaction to a single drug may depend on one gene or on many genes. Scientists will therefore have to build up a large base of experimental knowledge about which genes and which drugs matter to each other before it is useful to test everybody's DNA before giving them medicines.

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[*See Also* **Vol. 1, DNA Sequencing; Vol. 1, Genetic Discrimination.**]

Genetic Discrimination

Description

Discrimination is when people are treated unfairly because of who they are. For example, not hiring someone for a job because they have a certain skin color or religion is discrimination. Genetic discrimination is discrimination based on differences in a person's genes.

Insurance companies have sometimes denied, limited, or canceled health insurance policies for certain people because they thought that those people's genes made them more likely to get sick (in which case they would collect insurance payments). Companies have also fired or refuse to hire people with possibly defective genes because they feared the expense of having employees fall sick. In China, the law allows the government to sterilize people with genetic defects (to perform surgery on them so they cannot have children) or forbid them to marry each other.

Scientific Foundations

DNA (deoxyribonucleic acid) is the long, narrow molecule that all living things use to reproduce themselves. It is also used as a cookbook for making the large molecules called proteins that cells need during life. Genes are sections of DNA that control the how proteins are made. All living things, from bacteria to people, have genes. Each human being has about 25,000 genes. Only identical siblings (like identical twins) have exactly the same genes.

Sometimes a gene is defective or missing, causing the person to suffer from a disease. Other genes only increase their owners' chances of having some disease. For example, there are genes that make people more likely to have breast cancer or to be overweight.

China's Eugenics Law

In 1993, the Chinese government proposed a new law, the Eugenics and Health Protection Law. It spoke of ''abnormal'' children as a burden on society and said that China had ''more than 10 million disabled persons who could have been prevented through better controls.'' In Gansu province, officials were already requiring supposedly defective women to be sterilized before marriage, and were seeking to sterilize 260,000 more (that is, to perform surgery on their sexual organs so that they could not have children). According to the national eugenics law, which was passed in 1994 and was still in force in 2006, ''serious hereditary disease'' is grounds for refusing a marriage license unless the partners agree not to have children. Genetic tests that examine DNA directly are one way of seeing if such diseases are present. As genetic testing becomes cheaper and quicker, it may be used to screen Chinese couples to see if they are to be allowed to marry—a form of genetic discrimination.

However, these genes do not guarantee that these things will happen. The outcome also depends partly on chance, diet, exercise, and other factors not controlled by genes.

Development

The idea of discriminating against some people because of inherited traits—or traits believed to be inherited—is ancient. Over two thousand years ago, Greek philosophers talked about the possibility of breeding human beings to make them better. This idea is called eugenics, a Greek word meaning "well-born."

In the early twentieth century, sixteen American states passed eugenics laws and caused thousands of people to be surgically sterilized. The Nazis, who ruled Germany from 1933 to 1945, also believed in eugenics. They pointed to the American sterilization laws as a good example and passed eugenics laws of their own. The Nazis sterilized about 2 million people whom they thought were unfit to have children. The Nazi policies of eugenics, euthanasia (killing of the sick), and genocide (killing of entire peoples) were so horrible that after World War II (1938–1945), most people in Europe and America turned against the idea of eugenics.

DNA was not mentioned by early eugenics policies because its role in heredity was not yet known. The DNA molecule was first decoded in the 1950s. In the 1990s, it became possible to quickly and cheaply decode any person's DNA using DNA sequencing machines. During

Words to Know

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

DNA sequencing: A method of finding out the sequence of base pairs in a DNA molecule.

Eugenics: A social movement in which the population of a society, country, or the world is to be improved by controlling the passing on of hereditary information through selective breeding.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Sterilization: An operation that makes a person unable to have children. Usually this is done by cutting or tying off the tubes that convey eggs or sperm to the sexual organs.

that decade, cases of employers and insurance companies discriminating against people because of their DNA began to occur. Although there have not been a great many such cases—as of 2005, they were apparently occurring at the rate of a few a week in the United States—people with hereditary disorders or risk are concerned that their genetic information might be used against them.

Current Issues

In 2000, President Bill Clinton signed an executive order stopping any part of the U.S. federal government from using genetic information in hiring or promotion decisions. In 2001, President George W. Bush announced his support for a law banning genetic discrimination by insurers and employers. In 2003, the Genetic Privacy and Nondiscrimination Act, which would ban all forms of genetic discrimination, was passed by the U.S. Senate and sent to the House of Representatives for a vote. The vote did not take place, however, and the bill was reintroduced in 2005 (109th Congress). As of August 2006 had not yet been passed, and there was still no U.S. federal law banning genetic discrimination. Some U.S. states and several European countries have already passed laws against genetic discrimination.

Some protection against genetic discrimination is given by the Health Insurance Portability and Accountability Act of 1996 (a U.S. federal law), which bans the use of personal medical information to discriminate against people in hiring and insurance. However, that act deals with diseases or disabilities that people already have, and genetic discrimination may happen to people for diseases or disabilities they do not have yet but are at risk for.

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[*See Also* **Vol. 1, Bioethics; Vol. 1, DNA Fingerprinting; Vol. 1, DNA Sequencing; Vol. 1, Genetic Testing, Medical; Vol. 3, Government Regulations.**]

Genetically Modified Foods

Description

When an organism's genes (its genetic materials) are changed in a laboratory, the organism is called genetically modified or transgenic. Genetically modified foods are products that contain transgenic animals or plants as ingredients.

Genetically modifying food sources can make them bigger, stronger, and more nutritious. Changing genes in plants can protect them against disease. It can also help them survive when exposed to herbicides (chemicals used to kill weeds and plants) and insects.

There are many uses for genetically modified foods. For example, in parts of Africa, people eat large amounts of rice. Regular rice is not very nutritious, so scientists have genetically modified rice plants. These modified plants produce proteins that give their rice extra iron and vitamins. Scientists have also modified pigs to produce healthier meat and coffee plants to produce decaffeinated coffee beans, among other things.

Scientific Foundations

Genes are the basic units of heredity. They are contained within a double-stranded structure called deoxyribonucleic acid (DNA). The sequence of genes contains the instructions that tell cells how to create particular proteins. Proteins are primary components of living cells. How these proteins are produced determines what traits an animal or plant will have.

In nature, genes are passed from one generation to another. The genes of the parent determine which genes the offspring will have.

Today, scientists can add or change genes in a lab to create animals and plants with certain traits.

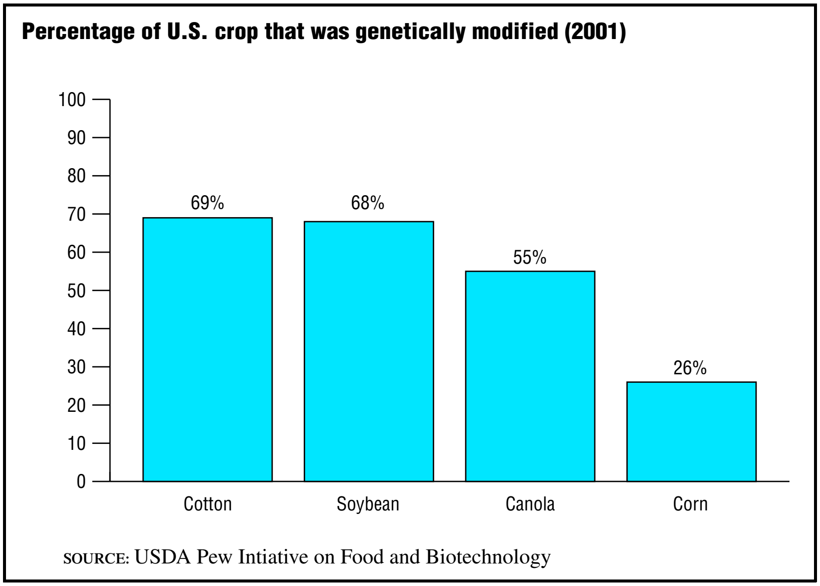
Should your refrigerator be condemned?
WHAT IS THE FDA TRYING TO FEED US?
STOP GENETICALLY ENGINEERED FOODS!
Sustain
DA:
+ = ?
CAN ANSWER
Give Me
TRU
OO

Demonstrators in Chicago protesting the availability of genetically modified foods. *Photograph by Associated Press/AP.*

Development

The idea of creating plants with specific traits is ancient, but it started as a science with the studies of an Austrian monk named Gregor Mendel (1822–1884) in the 1860s. Mendel discovered how plants passed their traits from one generation to another. Botanists (scientists who study plants) used his discovery to help them breed plants to have desired traits, such as sweeter fruit or extra seeds. This selective breeding took time. Scientists had to try different combinations to see which ones worked. Animal breeding worked in almost the same way. Scientists would mate animals that had the desired traits to try to create more animals with those same traits.

Cotton, soybeans, and canola (rapeseed) are the most commonly genetically modified crops. *Graph by GGS Inc.*



Scientists from three different research groups in Belgium and the United States were the first to make genetically modified plants. In the early 1980s they used bacteria to put a gene from one plant species into another plant species. One of the groups inserted a bean gene into a sunflower plant.

To genetically modify an animal or plant, scientists first have to find the gene that controls the trait they want to change. Then, they separate that gene and make many copies of it in a lab. Finally, they put the copied genes into animals or plants.

There are a couple ways to insert new genes in plants. The first uses a type of bacteria called *Agrobacterium* to transfer the gene. The *Agrobacterium* contains a circular piece of DNA called a plasmid. When the bacterium infects the plant, it copies its genes through the plasmid into the plant's genes. Another way to insert the gene is with a gene gun. The gun shoots tiny gold balls coated with the changed DNA into the plant's cells. Those genes then become part of the plant's DNA.

To genetically modify an animal, scientists combine its DNA and the DNA from another animal. They first cut the DNA using special enzymes (proteins that trigger chemical reactions in the body). Then they join the different animals' DNA together. A needle is used to insert the new genes into a fertilized egg or embryo (an animal in its earliest stages of development). The fertilized egg or embryo is then implanted in the mother's uterus

Combining Genes

In 1973, Herbert Boyer (1936–) of the University of California and Stanley Cohen (1935–) of Stanford University were the first scientists to combine genes from two different species in a lab. The method they discovered is called recombinant DNA technology (a method for cutting and joining together DNA from different species). It paved the way for genetically modified foods. In 1974, a German scientist named Rudolf Jaenisch inserted foreign DNA into mouse embryo cells. The mice carried the new DNA in their tissues. They were the first transgenic animals.

(the organ in a female's body in which the fetus develops). The gene becomes part of the embryo's cells. Another way to insert the gene is to use a virus or bacterium to carry the new gene into the animal's cells.

Current Issues

People who support genetically modified foods argue that they can help people who live in areas with poor growing conditions. They believe these foods can help end world hunger. Those on the other side of the debate worry about the safety of genetically modified foods. They fear that mixing genes from different species could create strange new animal and plant breeds.

Environmental groups worry that genetically altering foods could be dangerous to human health. They are not sure what effects genetically modified plants and animals might have on the people who eat them. Critics call these foods "Frankenfoods" because they have been pieced together using genes from different species.

One specific concern is that a gene might mistakenly be taken from a plant to which many people are allergic. For example, if a gene taken from a peanut were inserted into soybeans, it could cause the soybeans to produce peanut proteins. Those proteins could trigger a reaction in anyone who was allergic to peanuts. Another worry is that genetically modified plants might breed with the plants growing around them. Then the wild plants could pick up the traits from the modified plants. This cross-breeding could create problems such as weeds that herbicides cannot kill.

Words to Know

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Genetically modified food: A food product that contains a genetically modified plant or animal as an ingredient.

Transgenic: A genetically engineered animal or plant that contains genes from another species.

Virus: A very simple microorganism, much smaller than bacteria, that enters and multiples within cells. Viruses often exchange or transfer their genetic material (DNA or RNA) to cells and can cause diseases such as chickenpox, hepatitis, measles, and mumps.

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[*See Also* **Vol. 2, Alfalfa, Genetically Engineered; Vol. 2, Corn, Genetically Engineered; Vol. 2, Cotton, Genetically Engineered; Vol. 2, Genetic Engineering; Vol. 2, Genetically Engineered Animals; Vol. 2, Genetically Modified Organisms; Vol. 2, Rice, Genetically Engineered; Vol. 2, Transgenic Animals; Vol. 2, Transgenic Plants.**]

Genomics

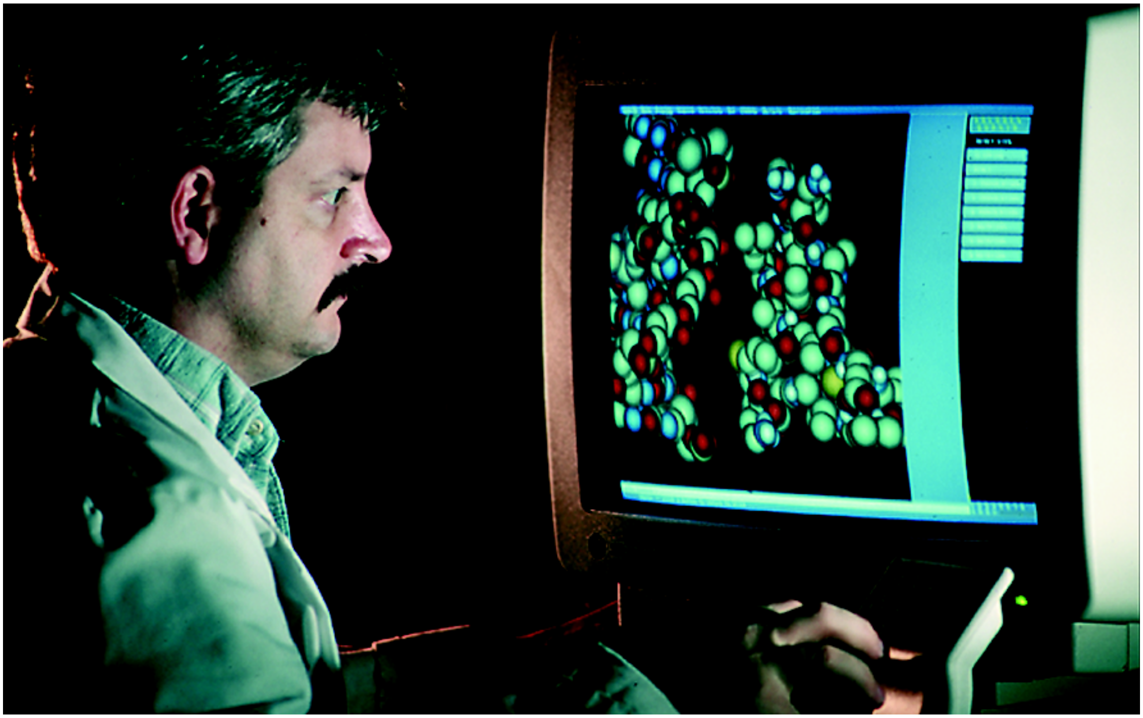
Description

The study of the sequences of genes within living things is called genomics. Genes are the basic units of heredity. Sequencing means that the structure of deoxyribonucleic acid (DNA) from a particular organism is discovered—what scientists called mapped. Specifically, genomic scientists identify and analyze the structure of genes within segments of DNA. Inside any organism, the complete set of chromosomes—or all the genetic information contained in genes—is called its genome. The set of chromosomes inside people is called the human genome.

Genomics is especially important in biology and medicine, and in industries such as agriculture and food production. Although the study of genomics is still in an early stage of development, it promises to provide valuable information for the discovery and treatment of human diseases. For example, a genomic test has been developed to diagnose breast cancer in women and to determine how likely it is that each woman will benefit from treatment to stop the cancer from growing inside her body.

Scientific Foundations

DNA is a molecule that contains the genetic code of a living thing, or the physical characteristics that are passed down to a child from his or her parents. Its structure is similar to a ladder that has been twisted into the shape of a winding staircase—what scientists call a twisted double-strand double helix (HEE-licks). All living things that contain cells have DNA. In mammals, such as humans, the pieces of DNA are grouped into structures called chromosomes (KROH-ma-sohmes), which are located in the nucleus of each cell. The genetic material



Scientist designing complex chemicals with the help of a computer. Scientists can use genomics to specially design drugs for patients based on their genes. *© Richard Nowitz/ PHOTOTAKE NYC.*

that is needed for humans to develop and grow is contained in DNA. The hereditary characteristics that pass from one generation to the next are also contained in DNA. An example of a hereditary characteristic that is inherited from parent to child is the blonde hair of a son born to parents who both have blonde hair.

Development

Genomics developed from genetics (the study of heredity) when DNA was first sequenced in 1977 by the independent work of English biochemist Frederick Sanger (1918–) and American molecular biologists Walter Gilbert (1932–) and Allan Maxam. In 1980, the first genome was completely sequenced when a bacteriophage called Phi-X174 (a particular virus infects a bacterium) was mapped. In 1989, American physician-geneticist Francis Collins (1950–) and Chinese geneticist Lap-Chee Tsui (1950–) sequenced the first human gene.

In 1990, the Human Genome Project (HGP) began in the United States. It was a coordinated international scientific project to understand and map the human genome so that all of its genes would be identified. Other countries participating in HGP included France, Germany, Japan, and the United Kingdom. HGP members

Genomics Can Make Better Drinking Water and Potatoes

Sometimes water in remote areas, such as tropical vacation spots, is not fit to drink. It makes people sick because of contamination with tiny, one-celled organisms called protists. These organisms cause illnesses such as diarrhea and malaria. However, genomics research is investigating the genetic composition of protists with the hope of finding ways to prevent people from getting sick after drinking contaminated water.

Millions of people around the world eat potatoes every day. Potatoes provide many nutrients and are inexpensive to grow. However, potato crops are prone to a number of diseases. The 1845–1850 potato famine in Ireland is one familiar example of how a potato disease led to the deaths of millions of people and forced large numbers of people to leave Ireland and move to other countries. Genomics research is exploring ways to grow stronger and more disease-resistant potatoes without the need for chemicals.

identified about 20,000 to 25,000 genes in the nucleus of a human cell and mapped the location of these genes on the twenty-three pairs of human chromosomes. The Human Genome Project and Celera Genomics simultaneously released an initial draft of the human genome in February 2001. The HGP completed the final sequencing of the human genome (with 99 percent of the genome sequenced to a 99.99 percent accuracy) in April 2003.

Current Issues

There are two major issues that are generally in dispute related to genomics: genetic engineering and genetic information. Genetic engineering involves the deliberate changing of genetic materials in a laboratory. Changing genetic material, for example, will let doctors diagnose and treat many diseases and help scientists improve the safety of foods. It will also give scientists the ability to change the physical and psychological traits of people. If a woman has an inherited heart problem, doctors could alter her genetic material so her future children will not have this problem. Scientists could also alter such minor physical characteristics as hair color and height. Many people do not think it is ethical to change such traits by altering genetic materials.

Genetic information involves gathering and storing data related to a person's DNA. Many questions about how this information should be stored and used are being asked such as: Who should be given this information? Who should be in charge of storing the

Words to Know

Chromosome: A thread-shaped structure that carries genetic information in cells.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Genome: A complete set of the DNA for a species.

information? Questions about personal privacy and other ethical considerations concerning genetic information have yet to be resolved. Lawmakers, health insurance companies, medical organizations, and U.S. citizens will all take a part in answering these sensitive questions. As scientific capabilities increase, more genetic information will become available. Humans will—no doubt—face more difficult ethical and privacy questions about genomics in the future.

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[*See Also* **Vol. 1, DNA Sequencing; Vol. 2, Genetic Engineering; Vol. 1, Genetically Modified Foods; Vol. 2, Genetically Modified Organisms; Vol. 1, Human Genome Project.**]

Germline Gene Therapy

Description

Gene therapy is the treatment of disease by changing an organism's genes. Many diseases are caused by defective genes, including Huntington's disease, sickle-cell anemia, and cystic fibrosis. The word "germline" refers to cells that contain genes (segments of genetic information) that can be passed on to future generations. Sperm cells, egg cells, and the small cluster of cells that makes up the human embryo soon after fertilization of an egg by a sperm are all germline cells. The cells that produce egg and sperm cells are also germline cells. The rest of the cells in the body, which cannot pass on their DNA (genetic information) to offspring, for example muscle cells or skin cells, are called somatic or body cells. Gene therapy that changes DNA in somatic cells is called somatic gene therapy, and gene therapy that changes DNA in germline cells is called germline gene therapy.

The difference between somatic and germline gene therapy is that changes made to DNA in germline gene therapy could be passed on through all future generations. Changes made to DNA in somatic gene therapy disappear when the person who has been treated dies. Germline therapy is a form of genetic engineering of human beings.

Scientific Foundations

Many genetic diseases are caused by defective genes (short sections of DNA, deoxyribonucleic acid) that keep certain substances from being made by the body's cells. For example, cystic fibrosis afflicts people who lack a working gene for making a certain protein, cystic fibrosis transmembrane conductance regulator (CFTCR for short).

On Losing One's Heads

One possible use for germline modification of embryos was proposed by a British scientist in 1997. The scientist, Jonathan Slack, announced that he had learned how to grow headless frogs by manipulating genes in the embryo. Why not, he said, grow headless human embryos and use them as a source of organs for transplant into sick people? Since the embryos would have no brains, they would not be human, he argued. They could be grown in artificial wombs outside any human body. (A prototype of such a womb was announced in 2002.) Some thought that the idea was horrible. ''This sort of thinking beggars belief,'' said an animal ethicist at Oxford University, Andrew Linzey. Another British biology professor said he thought the idea presented ''no ethical issues'' and added that whether it would be done was only a question of what he called ''the 'yuk' factor''—whether or not the public would be too grossed out by the idea to allow it.

Cystic fibrosis might be treated by giving a child's cells the gene they need to make CFTCR. This can be done in two ways. The first is to take cells from the patient's body, genetically engineer those cells to give them a working copy of the gene for CFTCR, and put those cells back into the body. The engineered body cells will then make the protein that the body needs. The second is to change the DNA of the parents' egg and sperm cells before the child is conceived, or to change the DNA of the first few cells (embryonic stem cells) that appear after fertilization of the egg. This second method is germline gene therapy.

Development

Gene therapy was not possible until the 1980s, when laboratory methods for changing DNA became available. Somatic gene therapy was first attempted in experiments in the 1990s. As of 2006, somatic gene therapy was still in the experimental stages, with some successes and some failures. Germline gene therapy is more difficult, although problems were being solved one by one in the early 2000s. By 2006, researchers had changed genes in mouse sperm before conception and in human embryonic stem cells. It seemed that the ability to do germline therapy could not be many years away.

Current Issues

To use the word "therapy" assumes that there will be benefit. There are many genetic diseases that might be treated with germline gene therapy. On the other hand, scientific critics point out how hard

Words to Know

Cystic fibrosis: A fatal disease in which a single defective gene prevents the body from making a protein, cystic fibrosis transmembrane conductance regulator.

Germline: Cells that can pass their DNA on to future generations, including egg and sperm cells and a few other types.

Somatic: Cells that are part of the body but are not in the germline (able to pass their DNA on to future generations) are somatic cells. Any type of cell in the body that is not a sperm or egg cell.

it is to control exactly what happens when genes are changed. In one mouse experiment, for instance, germline gene therapy cured a hereditary genetic disorder, but the later generations of mice that no longer had the original disorder had a higher rate of cancer.

Some scientists have already talked enthusiastically about changing future generations through germline manipulation so that they are better at computers, more musical, or more "emotionally stable." But this raises obvious questions about right and wrong. For example, some people might think that being "emotionally stable" means being obedient, non-rebellious, easy to control—a born slave. Who is qualified to decide what kind of emotions future generations of people should have?

However, some people—some scientists, some not—believe that the time has come for the human race to, as they put it, take charge of its own evolution. They believe that changing the nature of the human body and combining the human body with computers will increase freedom and happiness.

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[*See Also* **Vol. 1, Bioethics; Vol. 1, Somatic Cell Therapy; Vol. 1, Gene Therapy; Vol. 1, Therapeutic Cloning.**]

HapMap Project

Description

HapMap stands for Haplotype Map. A haplotype is a pattern of genetic differences shared by some individuals of a species, but not by all. The International HapMap project is an effort by several countries to identify common human haplotypes, creating a haplotype map for several major human groups (African, European, Asian). This map will be used to find out which genetic differences increase the risk for certain diseases. Scientists hope this will help them develop new ways to prevent, diagnose, and treat disease. The HapMap will describe the common haplotypes, where they are located in the human genome (the complete set of a species' genes), and which human populations tend to have specific haplotypes.

Scientific Foundations

Genes are the chemical code-words that tell living cells which proteins to make. Slightly different genes produce slightly different proteins. Some of these differences are harmless, but others can cause disease or make an organism more susceptible to certain diseases.

Genes are passed down from one generation to the next in the deoxyribonucleic acid (DNA) contained in most cells of every living thing. In species that reproduce sexually, half the genes in each offspring are from the male parent and half are from the female. When the genes of the offspring are first put together, the genes of the two parents are broken into sections and shuffled together randomly. Some genes tend not to get separated during this shuffling process, and so these genes are inherited together down through the generations. Bundles of genes inherited together

Still Evolving

Biologists studying results of the HapMap Project found evidence that human beings have been evolving as recently as the last 5,000 to 15,000 years. That may sound like a long time, but humans with bodies and brains basically the same as our own have existed for about 200,000 years. In biological terms, 5,000 years ago is very recent.

Since the DNA samples used in the HapMap Project came from groups of African, Asian, and European descent, genetic differences between those groups can be discovered in the data produced by the project. The historical switch from a life based on hunting to one based on growing crops, which happened about 10,000 years ago, seems to have put selective pressure on many genes in different groups. The colonization of Europe by people out of Africa also caused some genes to become more common in people of European descent because the climate is so different in Europe.

Despite these group differences, scientists say that the idea of ‘‘race’’ has no strict biological meaning. All people are more or less related to each other.

can build up slight differences from similar bundles inherited by other groups of individuals. These slightly different bundles of genes are called haplotypes.

Development

The HapMap project could not begin until another project, the Human Genome Project, was finished. The Human Genome Project (1986–2003), mapped the twenty-four long DNA molecules (chromosomes) that transmit all physical human traits from one generation to the next. (Humans have twenty two pairs of non-sex chromosomes plus two sex chromosomes.) However, a single genetic map cannot completely describe the DNA of all human beings because the DNA of most human beings is slightly different from that of all others. Only a few people, like identical twins or triplets, have exactly the same DNA as someone else. Any other two people can have only 99.9 percent identical DNA. In 2003, when researchers completed the Human Genome Project and could map where the all the genes are in human DNA, they began to map where the slight differences in human DNA occur. This effort to map the variations in human DNA is the HapMap Project.

The HapMap Project began in 2003 and was done by university researchers and private companies in Canada, China, Japan, Nigeria, the United Kingdom, and the United States. It cost about $100 million and was paid for by government groups, including the National Institutes of Health in the United States.

Words to Know

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Haplotype: A group of genes that are inherited together by some people.

Protein: Complex molecules that cells use to form most of the structures and control chemical reactions within a cell.

The HapMap project collected blood samples from 270 people. (Red blood cells do not contain DNA, but there are other kinds of cells in blood that do.) Ninety were from Nigeria, forty-five from Japan, forty-five from China, and ninety from the United States. Such small numbers were good enough because the goal of the project was not to record all existing haplotypes, but only the most common ones. The HapMap project greatly advanced scientific knowledge of human genetics.

The complete haplotype map was released in October 2005. In 2006, the HapMap Project was still releasing small fixes to the map.

Current Issues

The haplotype map produced by the HapMap Project does not directly help human health. Its purpose is to help researchers track down the genetic causes of various diseases. This can be done by comparing the haplotypes of people who have a certain disease, such as cancer, with the haplotypes of people who are less likely to who have the disease, or who do not have it at all. If one haplotype is more common in the people who get the disease, then it is likely that a gene somewhere in the haplotype helps cause the disease. This makes it easier to identify the disease gene. Many diseases, including cancer, heart disease, and some mental problems, are caused partly by genes and partly by what biologists call environmental factors—poisons, viruses, poor diet, painful experiences, and so on. It may take years for new disease treatments to be created from the new knowledge provided by the HapMap Project.

If some populations turn out to be more genetically susceptible to certain diseases than others, this knowledge could be used as an excuse for discrimination against them. Scientists working for the HapMap Project also point out that many people have strong beliefs about their ancestral origins or their relation to other groups, and knowledge from genetic studies like the Human Genome Project and the HapMap Project may disturb those beliefs.

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[*See Also* **Vol. 1, DNA Sequencing; Vol. 1, Genetic Discrimination; Vol. 1, Genomics; Vol. 1, Human Genome Project.**]

Heart Disease Drugs

Description

In medicine, the terms heart disease or cardiac (cardiac means heart) disease are often sometimes used to refer to all diseases of the circulatory system—the heart itself, blood volume and pressure, and the veins and arteries through which blood travels. As of 2006, at least 88 drugs were being used for disorders of the heart and circulatory system. Some were centuries old, but others had been developed only in the last few years.

Heart disease drugs are divided into groups based on how they affect the body. One way of grouping them is as follows:

Blood pressure medicines. Blood circulating through the body is under pressure, like water in a faucet. If the pressure is too low, a person will feel sick and faint. If the pressure is too high, it can cause strokes (stoppage of blood flow to part the brain), kidney damage, and other problems. To raise blood pressure, doctors sometimes tell patients to eat extra salt and drinks lots of water. Lowering blood pressure often must be done using drugs. Drugs that are used to lower high blood pressure (also called hypertension) include beta blockers, angiotensin-converting enzyme (ACE) inhibitors, and diuretics (water pills), among others.

Antiarrhythmic agents. The heart can beat poorly by going too fast (tachycardia, pronounced tack-ih-CAR-dee-ah), going too slow (bradycardia, pronounced brad-ih-CAR-dee-ah), or by beating irregularly (arrhythmia, pronounced ah-RITH-mee-ah). Different drugs are used to treat these different kinds of abnormal heartbeat.

Anticoagulants. Coagulation is when blood clots or turns to a solid. This is a good thing when the skin is broken because it stops bleeding. Inside the body, however, coagulation can be deadly. If it happens in blood vessels that supply oxygen to the brain or heart,

The Effects of Aspirin

Aspirin has long been known to reduce the ability of the blood to clot or solidify. This can be a good thing, in moderation; for over twenty years, doctors have been recommending that some of their adult patients take small doses of aspirin to reduce the chances of stroke and heart attack. In 2006, however, a surprising result was found. In a study of over 90,000 adults taking a small amount of aspirin every day, it was found that aspirin decreased the number of heart attacks being suffered by men by almost a third (32 percent), but did not affect the heart-attack rate in women at all. On the other hand, aspirin decreased the number of strokes in women by 17 percent—yet did not affect the stroke rate in men. Researchers do not yet know why the genders react so differently to aspirin.

part of the brain or heart can die, which can be fatal. Anticoagulants are drugs that make the blood less likely to coagulate. One of the most popular anticoagulants is aspirin, also taken as a pain medicine. Adults who are at risk for heart attack or stroke may be advised by their doctors to take about 80 milligrams of aspirin a day (about a tenth of what one would take for headache).

Scientific Foundations

Heart drugs work on the body in many different ways. Those that affect how the heart beats, for example, do so by affecting how substances that are naturally present act in the body. For example, the nerve cells that control how hard and how fast the heart beats become more active when they are in contact with hormones such as adrenaline (a chemical that is released into the blood when a person is frightened or angry, and in lesser amounts at other times). These chemicals are sensed by molecules called beta-adrenergic receptors that stud the surface of these nerve cells. Chemicals that block the ability of the beta-adrenergic receptors to sense chemicals like adrenaline are called beta blockers. Beta blockers make the nerves less excitable, with the result that the heart beats more slowly and fully. Some other heart medications act by affecting how much of the element calcium can enter heart muscle fibers from the fluid around them. Others, such as aspirin, act by completely different means. Because the circulatory system is so complicated, there are many ways it can be medicated.

Development

The function of the heart was not known until 1616, when English doctor William Harvey (1578–1657) announced that he had discovered the nature of the circulatory system. Harvey showed that the

Words to Know

Arrhythmia:	Any abnormal rhythm of the heart, which can be too rapid, too slow, or irregular in pace; one of the symptoms of anxiety disorder.
Bradycardia:	Too slow a hearbeat.
Cardiac:	Having to do with the heart.
Clotting:	The solidification of blood in response to a wound: coagulation.
Coagulation:	The solidifying or clotting of blood. Beneficial when used by the body to seal a wound; harmful if it occurs inside blood vessels.
Hypertension:	High blood pressure.
Tachycardia:	An elevated heart rate due to exercise or some other condition such as an anxiety attack.

heart pumps blood through the arteries and veins of the body in a closed loop—or, rather, two closed loops, one for the lungs and one for the rest of the body. With this basic understanding, modern medical treatment of the circulatory system began to evolve.

One of the earliest medications for heart conditions, which is still in use, is digitalis. Digitalis is extracted from the foxglove plant. Its use for heart problems was first described by English physician William Withering in 1785. The cardiac benefits of aspirin were first realized in the 1940s, but aspirin was not prescribed regularly for heart attack and stroke until the late 1980s and early 1990s. Most other modern heart medications are the products of research over the last few decades. New medications are always being developed.

Current Issues

Almost all medications have undesirable side effects. For example, beta blockers can cause chest pain, shortness of breath, dizziness, and disturbed sleep. Antiarrhythmic agents can actually make an irregular heart rhythm worse instead of better. They can also cause nausea, vomiting, diarrhea, low blood pressure, and headache. Aspirin can cause nausea, vomiting, diarrhea, and other problems. Research is going on all the time to create heart medications that treat diseases better while having fewer side effects. It is difficult and expensive, however, to develop a new drug, and many new drugs turn out to cause new side effects.

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[*See Also* **Vol. 1, Aspirin; Vol. 1, Blood Transfusions; Vol. 1, Blood-Clotting Factors.**]

HIV/AIDS Drugs

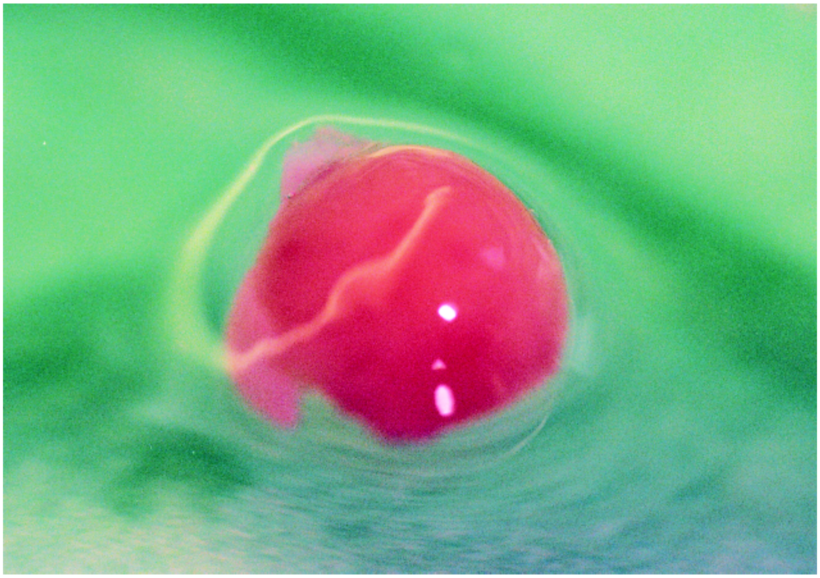
Description

HIV is short for "human immunodeficiency virus." Viruses are tiny germs that live inside other cells and cause disease.) HIV causes the disease AIDS (short for "acquired immunodeficiency syndrome"). Immunodeficiency is a deficiency or lack in the immune system, which is the body's defense against foreign attackers that cause disease.

HIV invades cells in the immune system and forces them to make more virus. This weakens and kills the cells. When too many immune-system cells have died, other germs can attack the body easily and can cause death. HIV/AIDS drugs are medicines that slow down HIV's spread in the body. As of 2006, there was no cure for HIV. HIV/AIDS drugs could not destroy the virus completely. They did enable some people to live longer with the disease.

The AIDS virus mutates quickly. That is, its genetic material—which, unlike that of most living things, is RNA, not DNA—suffers frequent changes or mistakes (mutations) as the virus reproduces. Some of these mutations are harmful to the new generations of virus, but a few make the virus more resistant to HIV/AIDS drugs.

Because HIV can quickly evolve resistance to a single drug, anti-HIV drugs are given in mixtures of three or four. This is called combination therapy. It is harder for HIV to evolve resistance to three drugs than to one drug. If the patient does not miss many doses, it can take about 10 years for the virus to evolve resistance to the combination therapy. When resistance does evolve, doctors switch the patient to a different combination therapy.



An organ-like group of cells created through genetic engineering that produces anti-HIV antibodies and CD4 receptors, another drug treatment for HIV/AIDS. © *Vo Trung Du/CORBIS SYGMA.*

As of 2006, AIDS had killed about 25 million people since 1981.

Scientific Foundations

HIV is a retrovirus. A retrovirus is a kind of virus that contains not DNA—the hereditary material of all other living things—but RNA, which cells usually use only to copy protein recipes from DNA. In order to force a cell to make new virus, HIV's RNA must first be copied into DNA. The cell is then tricked into making new copies of the virus using this DNA. Anti-HIV drugs (called antiretrovirals) interfere with some part of this cycle. Some antiretrovirals may prevent viruses from attaching to cells, others interfere with the construction of new virus particles in the cell, and others interfere with the working of reverse transcriptase.

Development

AIDS was discovered in 1981, when a rare type of pneumonia (infection of the lungs) was found in five gay men in Los Angeles, California. (It was soon learned that most of the people with AIDS worldwide are not gay.) In 1983, the HIV virus was found to be the cause of AIDS, and in 1987 a drug called azidothymidine (AZT) was discovered that could slow down HIV's reproduction. AZT is still used against AIDS, along with some twenty other, newer drugs.

Needed: HIV Drugs for Kids

In 2005, about three million people died of AIDS, about 600,000 of them children. Many babies are born every year with HIV, and half die before the age of two. In 2005, the international aid group Doctors Without Borders said that one reason for this high rate of infant death is that drug companies do not make combination-therapy pills small enough for young children. Doctors in poor countries, where most babies with AIDS are born, must therefore chop or crush pills meant for adults. The doses children receive are not always the right size, and this helps AIDS evolve resistance to the drugs and become deadly. Doctors Without Borders called on drug companies to develop more ‘‘child-friendly’’ versions of combination-therapy pills.

As of 2006, there was still no proven vaccine for HIV. (A vaccine is a substance which, given to a healthy person, prevents them from being infected by a certain virus or bacteria [one-celled germs that can cause diseases].) However, as of August, 2006, nine separate studies in the United States were testing experimental HIV vaccines.

Current Issues

AIDS continues to spread quickly in Africa, where about 25 million people had the virus in 2006. The United Nations estimated in 2005 that as many as 90 million Africans might die from AIDS over the next twenty years—a tenth of the population—unless more is done to stop the spread of AIDS there. Some groups, such as Doctors Without Borders, have accused the U.S. government of blocking the use of cheaper, non-brand-name AIDS drugs and of three-in-one combination therapy pills in order to protect the profits of large drug-making companies. The U.S. government has denied the charges and points to global AIDS spending by the United States, up from $2.4 billion in 2004 to $3.2 billion in 2006. Critics responded that the amount was still small for a country as rich as the United States, which, according to its own Defense Department, was spending about $4.5 billion per month on the war in Iraq as of August, 2006. The U.S. Food and Drug Administration approved a three-in-one pill for countries receiving U.S. AIDS assistance in July 2006.

Words to Know

Retrovirus: A virus whose genetic material is RNA (ribonucleic acid), not DNA.

RNA: Ribonucleic acid. Used by most cells to copy protein recipes from DNA; in retroviruses, RNA is the primary genetic material.

Vaccine: A product that produces immunity by inducing the body to form antibodies against a particular agent. Usually made from dead or weakened bacteria or viruses, vaccines cause an immune system response that makes the person immune to (safe from) a certain disease.

Virus: A very simple microorganism, much smaller than bacteria, that enters and multiples within cells. Viruses often exchange or transfer their genetic material (DNA or RNA) to cells and can cause diseases such as chickenpox, hepatitis, measles, and mumps.

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Human Genome Project

Description

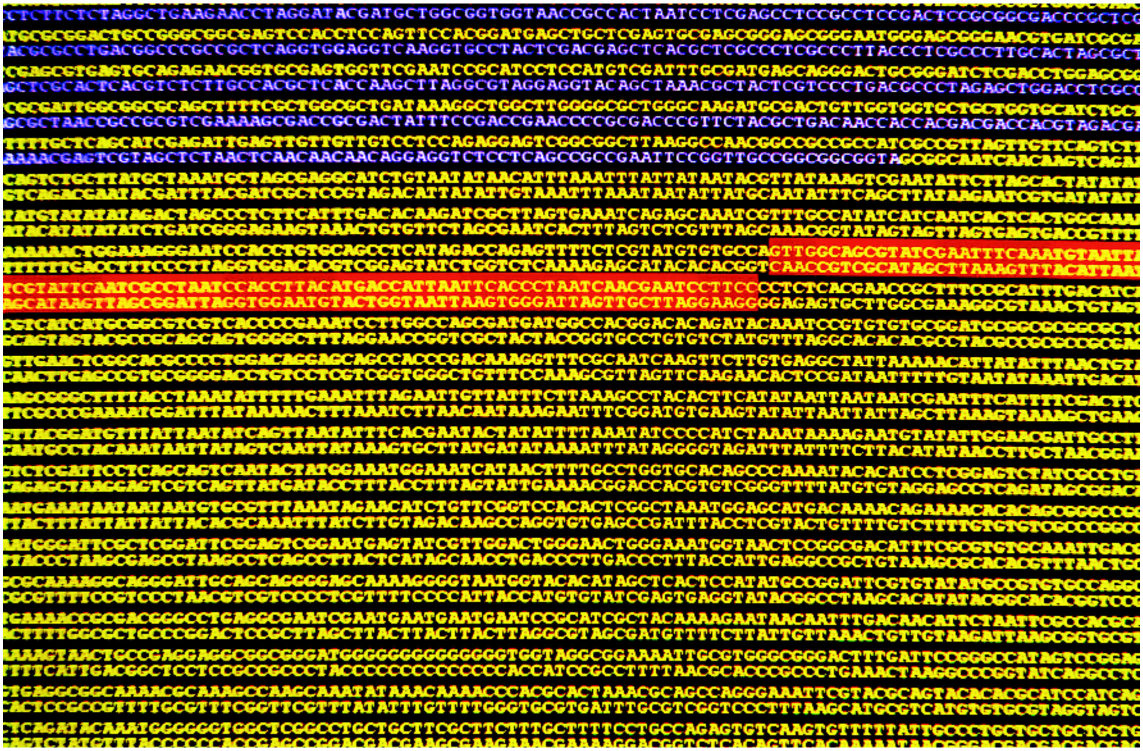
The Human Genome Project is a worldwide program with the goal of identifying all the genes in human DNA (deoxyribonucleic acid—an organism's hereditary material), discovering how they are arranged, and storing the information in a place where scientists could later study it. Scientists believed that the number of genes in the human body ranged from 50,000 to as many as 140,000. Researchers involved in the project also studied the genetic material in bacteria, flies, and mice.

Scientific Foundations

A genome is a genetic map, or blueprint, of an entire organism. Genome information is contained in tiny molecules of DNA, which are found in nearly every cell of an organism. DNA is packaged into sections called genes. Genes are the basic building blocks of the human body. Each gene contains instructions telling cells how to produce a particular chemical. Genes and the chemicals they code for, called proteins, help determine what a person looks like and how his or her body works. Broken (defective) or missing genes can lead to disease.

Development

In 1985, scientists started talking seriously about the idea of mapping the entire human genome. It was a complicated task, and some scientists were not sure it could be done. By outlining the order of DNA in the human body, the scientists hoped it would eventually lead to new ways to spot diseases passed down through families. In 1986, the United States Department of Energy (DOE) announced its Human Genome Initiative. The initiative pushed for the development of new tools for scientists who study living things (biologists).



Section of the human genome mapped for the Human Genome Project. The letters A, T, C, and G stand for the components of DNA, which combine to spell out the genetic code. *Raphael Gaillarde/Getty Images.*

U.S. scientists originally thought the project would take fifteen years. New tools and computer software helped scientists finish the project two years ahead of schedule. Researchers had mapped out all the genes for the human body by 2003. According to the NIH, the project revealed there were about 30,000 to 40,000 genes in the human body; this number was a lot smaller than expected. Scientists now had a map that showed their exact locations. The International Human Genome Sequencing Consortium published their findings in two scientific journals.

Identifying the number and order of genes in the human body was the first step in the Human Genome Project. The next step is to identify how each gene individually affects human life and to determine how all the parts of cells work together. This will likely take several years. Scientists do not know the function of more than half of the genes identified. It is believed that knowing how each gene works will change human health because scientists will better understand how certain diseases occur. This could lead to better medicines that target the exact cause of a disease and blood tests that tell which person has a specific gene or gene problem. Scientists have already identified genes responsible for breast cancer,

Project Participants

The United States Human Genome Project officially started in 1990. It was a team effort between the DOE and the National Institutes of Health (NIH). Researcher Ari Patrinos lead the DOE effort, and American doctor Francis Collins supervised the program at the NIH. The U.S. government gave money to support the program. Other countries soon joined the project. At least eighteen countries set up their own human genome research programs, including Australia, Brazil, Canada, China, Denmark, France, Germany, Israel, Italy, Japan, Korea, Mexico, Netherlands, Russia, Sweden, and the United Kingdom. Private companies, including U.S.-based Celera, also set up programs. The race to map out the entire human genome soon became a heated scientific competition.

deafness, diabetes, and asthma. However, it could be ten to fifteen years before new drugs based on the information from the project become available for widespread public use.

Current Issues

The Human Genome Project has raised important concerns. Some people think that cracking the code to the human body could threaten the natural course of life. People who oppose the project fear that someday people could pay to create babies with perfect genes, and that people with genetic problems may be considered to be of a lower class. Others question who should have access to a person's genetic blueprint. Many people want to keep such information private. Public genetic records could lead to genetic discrimination, in which insurers or employers would turn away a person with certain genes or gene problems (defects).

Some people are against testing for genetic diseases when there is no treatment available. Scientists have identified gene defects responsible for a number of diseases, but many of them cannot be corrected with modern medicine. Critics say that telling a person they have a genetic disorder when there is no treatment available does more harm than good. Recently, tests have been created to spot gene defects related to breast, ovarian, and colon cancers.

Another controversial issue regarding the Human Genome Project has been the cost. Millions of dollars have been spent on the research. Some people think the money could be better spent on research that has an immediate impact on human life.

Words to Know

Cells: The smallest living units of the body which together form tissues.

Deoxyribonucleic acid (DNA): The double-helix shaped molecule that serves as the carrier of genetic information for humans and most organisms.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Genetic disease: An inherited disease.

Genome: A complete set of the DNA for a species.

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[*See Also* **Vol. 1, Designer Genes; Vol. 1, Genetic Discrimination; Vol. 1, Genomics.**]

Human Growth Hormone

Description

Human growth hormone (HGH) is a chemical released from a pea-sized structure below the brain called the pituitary gland. The pituitary gland is considered the body's control center. It tells other glands in the body to produce chemicals (called hormones) that control body functions.

Scientific Foundations

Growth hormone helps children grow. Another name for this hormone is somatotropin. Some people make too much or too little growth hormone. This can lead to disease.

Too little growth hormone can cause a condition called pituitary dwarfism, meaning little growth. Children who do not make enough growth hormone are usually shorter than other children their age. They may have more fat around their stomachs and face, and lower-than-normal levels of sugar (glucose) in their blood. Adults who have damage to their pituitary gland may fail to make enough growth hormone. This condition, called adult growth hormone deficiency, causes weight gain, along with weak muscles and bones.

If a child's body produces too much growth hormone, a rare disorder called gigantism results. Gigantism causes bones to grow very fast. The person becomes very tall. People who have gigantism have very large hands and feet, and thick fingers and toes. If the body produces too much growth hormone after a person stops growing, the condition is called acromegaly. *Acro* means "end" and *megaly* means "enlarged." This condition usually strikes adults between age thirty and fifty. Cancerous tumors of the pituitary gland can cause too much growth hormone to be released.

A laboratory technician checks a blood sample during testing for human growth hormone, a banned subtance in athletic competitions. © *Reuters/ Corbis.*

Development

Cases of slowed and rapid growth have been seen for centuries. The Roman military commander Gaius Plinius Secundus (23–79 CE) wrote about families of short people (dwarfs) in Asia and Africa. Religious writings talked about giant people, particularly a giant man with twenty-four fingers and toes. The first medical description of acromegaly was published in 1886. French neurologist Pierre Marie (1853–1940) wrote about a condition that caused bones in the nose, jaw, fingers, and toes to become very large, and discovered it was caused by a tumor in the pituitary gland. Marie is credited with inventing the term acromegaly.

Because the pituitary gland sits at the bottom of the brain, many scientists did not experiment with it. However, in 1909 neurosurgeon Harvey Cushing (1869–1930) said he treated acromegaly by taking out part of a woman's pituitary gland. A few years later, two scientists each discovered that removing the pituitary gland caused slow growth.

Andre the Giant

Andre Rene Roussimoff, otherwise known as ''Andre the Giant'' (1946–1993), was born in Grenoble, France to normal-sized parents. He displayed symptoms of gigantism early in life, standing six feet, seven inches tall by the time he was a teenager.

Andre made the best of his condition and began a career in professional wrestling. He called himself the ''Eighth Wonder of the World.'' He was hired by the World Wrestling Federation to perform in America under the name Andre the Giant. He appeared in *Sports Illustrated* magazine, and began acting in television and movies. His most famous role was that of Fezzik, in the 1987 film, *The Princess Bride*.

Andre grew until he reached seven feet, four inches in height and five hundred pounds in weight. This continuing growth put a strain on his heart, which eventually could not keep up with the demands of his body.

Growth hormone was discovered in the 1920s. About thirty years later, scientists figured out how to remove growth hormone from the human pituitary gland. They gave it to children with growth hormone deficiencies and discovered it helped them grow. This discovery led to the development of growth hormone replacement therapy. The first growth hormone replacement therapy medicine was taken from the pituitary glands of dead bodies (cadavers). It was given through a shot (injection). Between 1958 and 1985, the medicine was used to treat more than 8,000 children with growth hormone deficiencies.

In 1985, scientists discovered that some people who had received the growth hormone made from dead bodies developed a deadly brain disorder called Creutzfeld-Jakob disease. The U.S. Food and Drug Administration (FDA) said that the medicine could no longer be sold. Scientists started looking for new ways to create growth hormone medicine.

The first artificial (synthetic) human growth hormone, called Protropin, was developed in 1985 by the Genetech corporation in San Francisco. A year later, the Indianapolis-based drug maker Eli Lily created an artificial human growth hormone that was exactly the same as the one produced by the human pituitary gland. They called their product Humatrope. In 2003, the FDA said the drug could be used to increase height in short children who did not have a growth hormone deficiency. By 2005, available synthetic growth hormones included Genotropin, Norditropin, and Saizen.

Current Issues

Numerous experiments have been carried out using human growth hormone. In recent years, medical researchers have wondered if human growth hormone could keep people from aging. Studies have

Words to Know

Acromegaly: A disease caused by the release of excess growth hormone, resulting in excessive growth of some bones.

Gigantism: A rare disease caused by the release of too much growth hormone while a child is still developing.

Genotropin: A human-made form of human growth hormone.

Growth hormone deficiency: A condition in which the body makes too little growth hormone.

Leukemia: A cancer of the blood-producing cells in bone marrow.

Pituitary gland: In humans, a structure (organ) below the brain that releases human growth hormone.

shown that adults who take human growth hormone lose fat while gaining a lot of muscle mass. How growth hormone effects normal aging remains a popular area of research.

Growth hormone helps the body metabolize (break down) the components of foods. The failure to properly break down such products can lead to conditions that cause excessive weight gain. Researchers have reported that a type of human growth hormone could be used to treat obesity.

Human growth hormone has also been given as an experimental treatment in certain patients whose intestines do not work properly.

There is concern that people may experiment with human growth hormone to improve their athletic abilities. Research shows some young athletes take growth hormone supplements illegally in hopes of putting on more muscle and building strength. Human growth hormone has not been shown to improve athletic performance but has many negative side effects.

Critics have questioned the FDA's approval of Humatrope for children who do not have growth hormone deficiencies. Some believe that the drug is too expensive (ten to twenty thousand U.S. dollars per year) to be used to boost a child's height by only a few inches.

Other research suggests that people who take growth hormone have higher rates of a type of cancer called leukemia. Common side effects of growth hormone include headaches and muscle pain.

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[*See Also* **Vol. 1, Protein Therapies.**]

In-Vitro Fertilization

Description

Fertilization is when an egg cell and a sperm cell come together to make an zygote, a cell that has all the DNA needed to make a new individual. In mammals (warm-blooded animals, including humans), fertilization happens inside the female, but it can also be made to happen in a glass dish. *Vitro* is the Latin word for glass, so fertilization in the laboratory is called in-vitro fertilization.

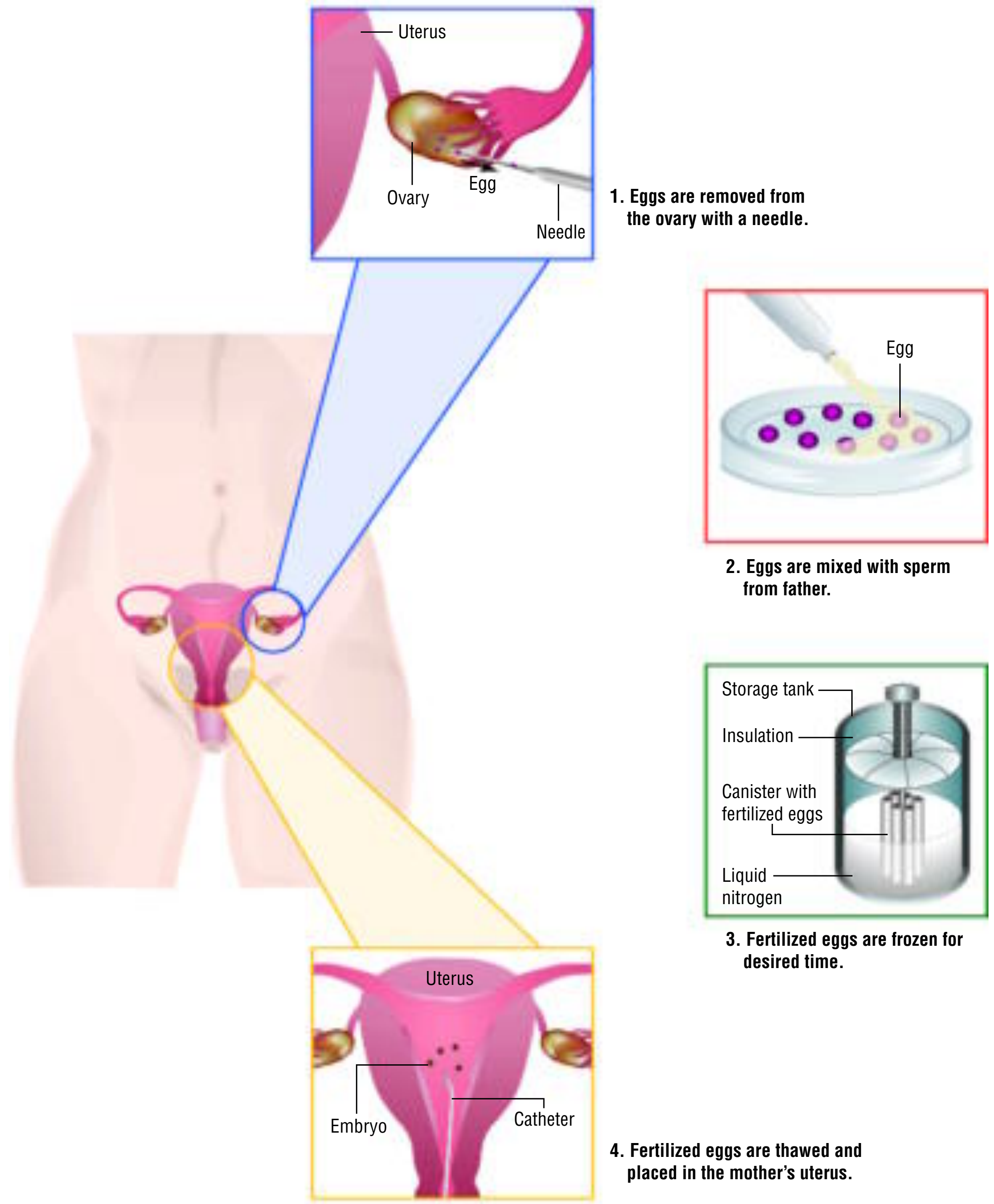
In-vitro fertilization (IVF) is used in cloning, animal breeding, and to overcome fertility problems in human beings. Fertility is the ability to get pregnant. To begin IVF, a woman is given a drug to encourage the growth of follicles on the ovaries. Follicles are small balls of cells that each contain an egg ready for fertilization. After about ten days, another drug is given that prepares the ovary (which stores eggs) to release the eggs. A needle is then inserted into the vagina and through its wall to suck prepared eggs from the ovaries. These eggs are combined with sperm in glassware to fertilize them.

The resulting fertilized cells (zygotes) are allowed to grow for two or three days until they are embryos containing six or eight cells. Several of the embryos are then put into the woman's uterus (the womb, where the baby will grow until birth) through a tube. If any of the embryos implant in the wall of her uterus and begin to grow, she is pregnant.

On average, a woman must go through three rounds of implantation before getting pregnant. In the United States in 2006, the cost per round was at least $7,500, making the cost of conceiving with IVF at least $22,500—often much more. For many people, therefore, IVF was not an affordable choice.

In-vitro fertilization

How human eggs are fertilized in the laboratory


Uterus
Ovary
Egg
Needle
Egg
Storage tank
Insulation
Canister with fertilized eggs
Liquid nitrogen
Uterus
Embryo
Catheter

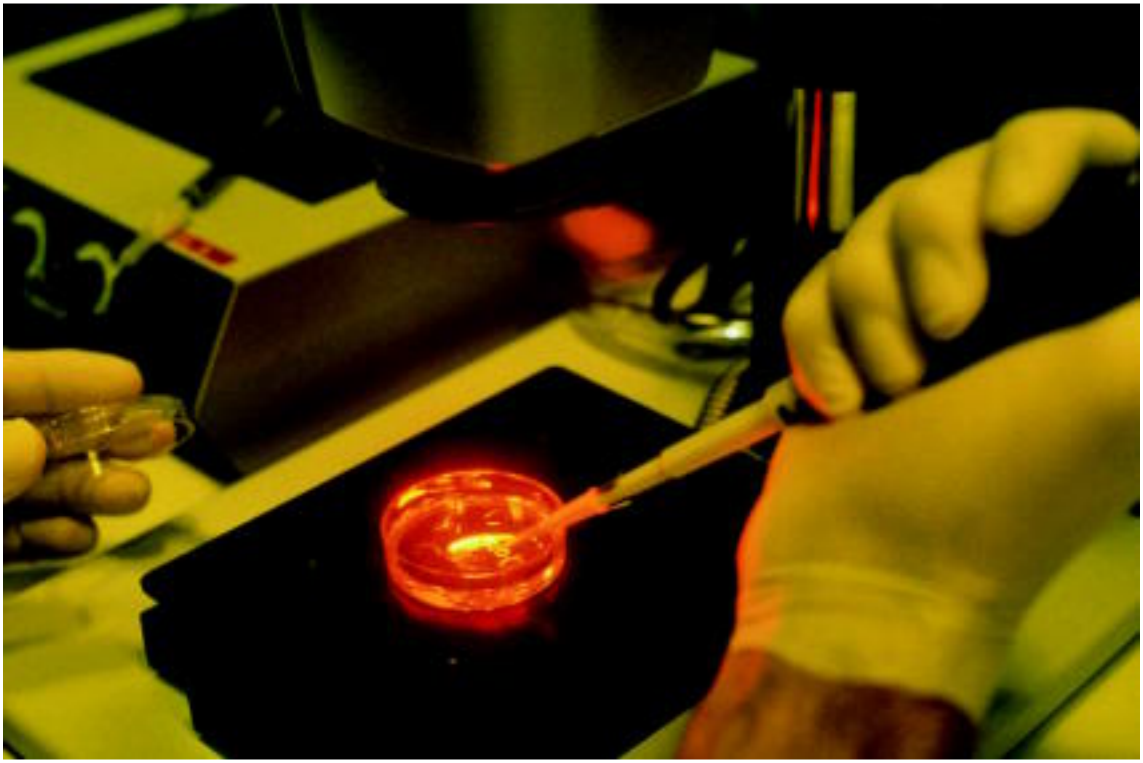
1. Eggs are removed from the ovary with a needle.

2. Eggs are mixed with sperm from father.

3. Fertilized eggs are frozen for desired time.

4. Fertilized eggs are thawed and placed in the mother's uterus.

During in-vitro fertilization, eggs and sperm are removed from the potential mother and father; the egg is fertilized in a lab; and the embryo is returned to the mother to grow until birth. *Illustration by GGS Inc.*



Technician injecting sperm into a laboratory dish containing a human egg in an in-vitro fertilization procedure. © *Owen Franken/Corbis.*

Scientific Foundations

Almost all living things pass on their DNA (deoxyribonucleic acid, their genetic information) to the next generation when they reproduce. DNA is present in almost every cell in humans. Throughout their lives, cells use their DNA copy as a recipe book to make large, complex molecules called proteins. Most cells in the human body contain or two copies of the human genome divided up into forty-eight microscopic packages called chromosomes. The egg cells produced by females and the sperm cells produced by males each contain only twenty-three chromosomes. When they come together, they produce a cell containing a new mixture of chromosomes with the correct number, forty-six. The fertilized cell divides into two, those two cells divide into four, and so on, beginning a growth process that can produce an adult person. In-vitro fertilization simply allows the beginning of this process to happen outside the female body instead of inside.

Development

Two doctors in Great Britain, Patrick Steptoe and Robert Edwards, began trying to solve conception-related infertility in 1966. They

500,000 Frozen Embryos

Today there are about 430 fertility clinics in the United States alone. These are medical businesses that use in-vitro fertilization (IVF) to help women become pregnant. Many of the embryos that are made during the IVF process never get used. They are not thrown away. Instead, they are kept frozen in liquid nitrogen, which is far colder than the freezing point of water. In 2002, the RAND corporation estimated that there were already 400,000 embryos in frozen storage; by 2006 there were probably more than 500,000. There is no agreement about what to do with these embryos. They could be used for stem-cell research, but religious conservatives view them as human beings and so consider their destruction for any purpose as murder. In 2001, President George W. Bush banned federal money for medical research using stem cells (special cells in that can grow into any other kind of cell) from leftover IVF embryos and has promoted what some call the ''adoption'' of leftover IVF embryos by women wishing to become pregnant. In 2005, the U.S. Food and Drug Administration declared that IVF embryos are ''tissue,'' not people.

were able to extract eggs from the body and fertilize them in vitro, but were not able to implant them successfully in a woman's uterus. They finally succeeded in 1977, and the world's first "test-tube" baby, named Louise Joy Brown, was born in July 1978.

Since that time, many thousands of babies have been born that were conceived in vitro. In 2005, it was estimated that about 1 percent of babies in the United States—more in some other countries, for example 4 percent in Denmark—were conceived using IVF.

Current Issues

The Catholic Church and some conservative Protestant groups oppose IVF. In the words of the official Catechism (statement of beliefs) of the Catholic Church, methods like IVF "dissociate the sexual act from the procreative act. The act which brings the child into existence is no longer an act by which two persons give themselves to one another," but one that "entrusts the life and identity of the embryo into the power of doctors and biologists and establishes the domination of technology over the origin and destiny of the human person." Furthermore, conservative religious groups view the fertilized egg cells that are produced by IVF as human beings. Since more fertilized eggs are produced in IVF than are used, IVF is, in their view, destructive of human lives.

Words to Know

Fertilization: The union of an egg cell with a sperm cell to make a zygote, or cell that may divide repeatedly to become an embryo and potentially a full-grown creature.

Genome: A complete set of the DNA for a species.

Zygote: The cell resulting from the fusion of male sperm and the female egg. Normally the zygote has double the chromosome number of either gamete, and gives rise to a new embryo.

Whether IVF is right or wrong is not a scientific question but a religious or ethical one. Disagreement about this question will continue in our society for the foreseeable future.

Children conceived using IVF are about 3.7 times more likely to have cerebral palsy (a disease of the nervous system) than children conceived naturally. In 2006, research showed that this is because children conceived using IVF have a higher chance of being born prematurely (too soon).

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[*See Also* **Vol. 1, Human Cloning; Vol. 1, Germline Gene Therapy.**]

Insulin, Recombinant Human

Description

Insulin is a hormone that is normally produced by specialized cells located in the pancreas (a gland found in the human abdomen). A hormone is a chemical messenger—a chemical produced in one tissue of the body and then transported to other tissues where it produces a reaction. The presence of insulin is critical in the regulation of the use of carbohydrates and fats consumed as food and used for energy by the body.

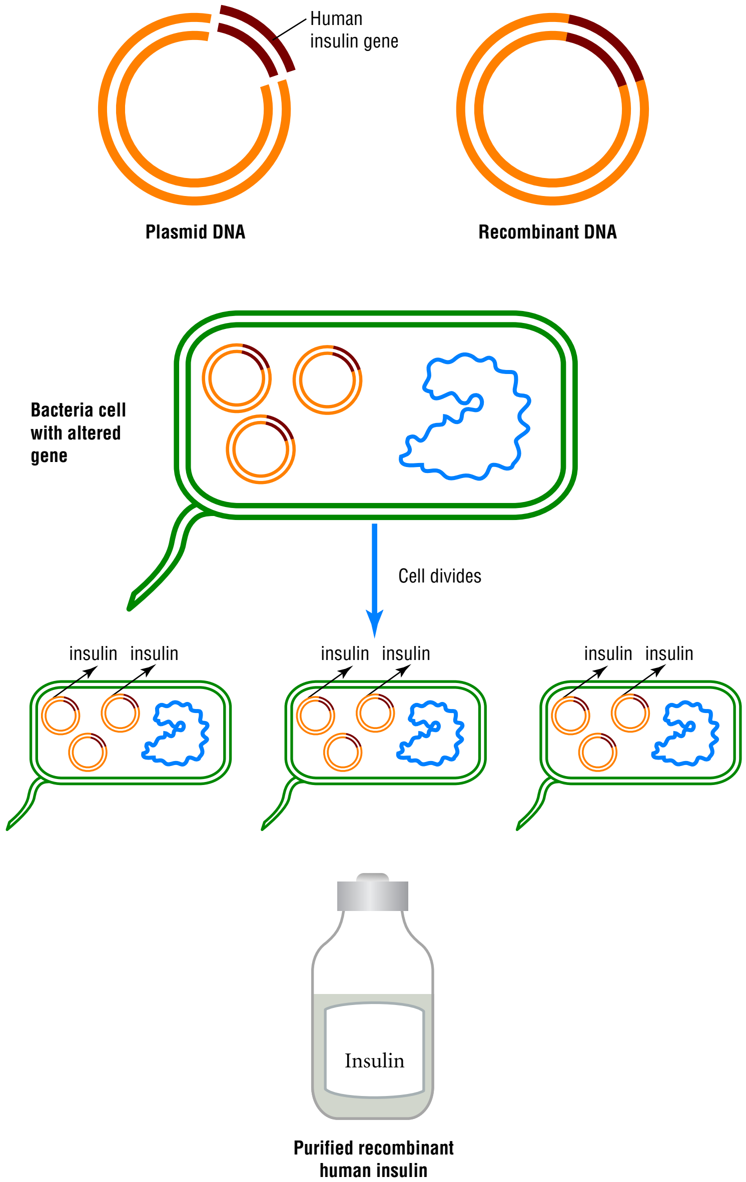
In the disease called diabetes, the production of insulin is abnormal or does not occur. As a consequence, the form of sugar called glucose either is not broken down properly or cannot be broken down at all into the smaller units that help power the body.

Scientific Foundations

The insulin from pigs and cows was sometimes given to diabetics (people with diabetes) as medicine, but the insulin from these animals is not identical to human insulin. This means that some people will develop an immune system reaction to the animal versions, which can be painful and potentially unhealthy in the long-term. The immune system is designed to identify foreign substances in the body and attack them, and it is this reaction that causes harm to the body. These concerns led to the use of recombinant DNA technology to produce recombinant human insulin, as described in the next section.

Insulin is a relatively small protein whose sequence is simple. Proteins are the primary components of living cells, and perform most of their vital functions. Insulin is made up of only fifty-one chemical parts called amino acids, whereas some proteins can be comprised of hundreds or thousands of amino acids. Thirty amino

Recombinant human insulin


Human insulin gene
Plasmid DNA
Recombinant DNA
Bacteria cell with altered gene
Cell divides
insulin
insulin
insulin
insulin
insulin
insulin
Insulin
Purified recombinant human insulin

The process of creating recombinant human insulin. Plasmids are structures that carry genetic information in bacteria. Once the bacteria produce more insulin as they divide, it can be extracted and purified into drug form. *Illustration by GGS Inc.*

Insulin Paved the Way for Biotechnology

The ability to deliberately insert the genes from one organism into the genome of another organism only came about in 1973. Almost immediately, researchers and commercial biotechnology companies recognized the potential of DNA technology in the manufacture of insulin. While the insulin obtained from pigs and cows was life-saving for diabetics, allergic reactions were possible. By harnessing the bacterium *Escherichia coli* to express the inserted human gene for insulin, a plentiful and profitable supply of insulin was ensured. By the end of the 1970s, recombinant human insulin was in the marketplace, demonstrating the potential for biotechnology. Over 130 recombinant drugs are now used to treat many types of cancer, arthritis, and for vaccines.

acids are arranged in one chain, and the remaining twenty-one are arranged in a second chain. The two chains are bonded together.

The genetic information that carries the instructions for assembling these amino acids is located on one of the arms of chromosome 11. (Humans have forty-six chromosomes.) To produce recombinant human insulin, this human is inserted into a bacterium (plural, bacteria). Bacteria are one-celled germs that exist in most places on Earth, and sometimes cause disease. The bacterium that is inserted with the human insulin gene is *Escherichia coli* (*E. coli*).

E. coli is normally found in the intestinal tract of humans and other mammals and does not cause disease. Other versions of the bacterium are not as harmless, and can contaminate food and water. For the production of insulin, the version of *E. coli* used has been deliberately crippled so that it cannot grow outside the test tube. After the human insulin gene has been inserted the bacterium, it then “knows” how to produce that insulin protein. When the bacterium divides, subsequent generations of bacteria also produce the protein. After the insulin is harvested from the bacteria cells, it is refined and made into medicine for diabetics. Large amounts of recombinant human insulin can be produced in this way.

Development

Since the discovery of insulin in 1921 by Canadian researchers Frederick Banting (1891–1941) and Charles Best (1899–1978), and their demonstration that the compound could cure diabetes in an animal model, diabetics who require insulin have relied on regular injections of the compound to function normally. In the past, the insulin that was routinely used by diabetics was obtained from pigs or cows.

Words to Know

Chromosome: A thread-shaped structure that carries genetic information in cells.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

***Escherichia coli*:** *E. coli*, a species of bacteria that lives in the intestinal tract and that are often associated with fecal contamination.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Hormone: A chemical substance produced by the body. Hormones are created by one organ of they body but they usually carry out functions in other organs or parts of the body.

Insulin: A substance made by the body (or by genetically engineered bacteria) that the body needs to regulate the amount of sugar in the blood.

Recombinant DNA: DNA that is cut using specific enzymes so that a gene or DNA sequence can be inserted.

With the development of techniques that permitted the genetic material (deoxyribonucleic acid or DNA) from one organism to be inserted and expressed in the genetic material of a different organism, the ability to harness bacteria for the production of human insulin was realized. In 2006, recombinant human insulin (marketed as Humulin®) was the overwhelming source of insulin for diabetics around the world.

Current Issues

The production of recombinant human insulin remains notable because it is still one of the few animal proteins produced by bacteria that is absolutely identical to the human counterpart. This accuracy of production, and the resulting overwhelming acceptance and approval of recombinant human insulin as a life-saver for diabetics continues to be a powerful example of the potential for biotechnology, in the face of vocal opposition.

Research continues into improving the yield of recombinant insulin, and in ensuring that its manufacture is free from contamination.

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[*See Also* **Vol. 1, Designer Genes; Vol. 1, Gene Therapy; Vol. 1, Pharmacogenetics.**]

Metabolic Engineering

Description

Numerous chemical reactions take place in the human body on a daily basis. Most of these reactions occur repeatedly in the same body systems. For instance, the digestive system controls to break down of food, whereas the circulatory system ensures proper blood circulation in the body. These biological systems are a series of chemical reactions. The combined effect of all the chemical reactions in the human body is referred to as metabolism. Metabolism is important to general health and growth.

Metabolic engineering consists of techniques that allow us to better understand metabolic processes that can be altered to benefit mankind. Metabolic engineering has the potential to contribute immensely towards the growth of health care, medical sciences, and various industries.

Metabolic engineering can be used to improve food production for such products as cheese, wine, and beer. It is helpful in finding cures for diseases, for the mass production of antibiotics, to improve agricultural practices, and to enable effective means of energy production. Metabolic engineering can also assist in the development of eco-friendly ways for cleaning up the environment.

Scientific Foundations

All living bodies, including plants and animals, are made of cells. Each cell in a body is programmed to carry out a number of chemical reactions. Metabolism comprises all of these reactions. There are two different types of metabolic processes. Anabolic reactions take place to form a compound (chemical molecule), while catabolic reactions are responsible for the break down of compounds. Enzymes are substances that catalyze (or speed up) metabolic reactions.

These genetically modified *E. coli* bacteria in solution make a drug called hydromorphone, an artificial version of morphine, a powerful painkiller. *James King-Holmes/Photo Researchers, Inc.*

Metabolic reactions typically follow set sequences, called metabolic pathways. Scientists study these pathways to understand the functioning of cells, tissues, organs, and eventually the complete body system. Enzymes catalyze each step in a cellular pathway, so determining the specific enzymes participating in a reaction is important. Metabolic engineering involves discovering and analyzing such metabolic pathways.

Development

Since the time English naturalist Charles Darwin (1809–1882) introduced his theory of evolution, people have known that minor changes occur from one generation to another. Although they share several

Metabolic Engineering as a Comprehensive Subject

Metabolic engineering is a multidisciplinary area requiring knowledge and implementation of other principles including recombinant deoxyribonucleic acid (DNA) technology (in which DNA from different organisms is combined), microbiology, cell biology, biochemistry, mathematical sciences, and chemical engineering.

similarities, children are different from their parents. Some of their differences are better suited for survival. Some do not have any effect, while others may be harmful. Nature always prefers those changes (also known as mutations) that increase survival rates of an organism. During the natural course of evolution, mutations accumulate over millions of years to such an extent that the organism showing modifications stops resembling the parent species and becomes a new species.

Metabolic engineering is a relatively new science that is developed on the underlying principles of evolution. It allows scientists to create mutations and study their effects in a much shorter span of time and in a laboratory setup. By modifying the genetic composition of cells, scientists can enhance desired mutations that either improve quality or increase production of various bioproducts (cheese, medicines, and so on) for industrial use.

Cells and their components are so small that it is difficult to study them in detail. Studying the genetic information in cells did not become possible until the advent of some sophisticated techniques such as the polymerase chain reaction (PCR), in which the smallest quantities of genetic material can be amplified to an extent where they can be easily examined.

Invented in 1985, PCR enables scientists to clone (copy) and investigate the genes responsible for the creation of various com-

How was Erythromycin Discovered?

Erythromycin, a common antibiotic for treating infections caused by bacteria, was discovered from a bacterium in 1952. Its structure was identified in 1965, and the process of its creation was published in 1981. However, it was only in the 1990s that its manufacture was completely understood. With the new information gained, researchers have now found a laboratory method for mass-producing erythromycin.

Words to Know

Anabolic:	To build the body. Often used to describe a group of hormones sometimes abused by athletes in training to temporarily increase the size of their muscles.
Catabolic:	To break down. The break down of complex molecules into simpler molecules.
Catalyst:	Any agent that accelerates a chemical reaction without entering the reaction or being changed by it.
Metabolism:	Chemical changes in body tissue that convert nutrients into energy for use by all vital bodily functions.

pounds the body uses. PCR also aids analysis of the complete genetic material of several organisms, allowing scientists to look at genetic differences across a population.

Current Issues

Metabolic engineering helped create several beneficial bioproducts—products derived through living systems. Microorganisms and single-cell creatures are much simpler than their multi-cellular counterparts and have less genetic material and fewer biochemical reactions to be investigated. Consequently, researchers are more successful in engineering metabolic pathways in microorganisms.

The primary objective of metabolic engineering is to improve human life. It is being used to create varieties of plants that are resistant to pest infestation, yield a higher quantity of produce, or generate more nutritious goods. Metabolic engineering has also been used to study heart and liver diseases.

Apart from the complexity of organisms, other issues have slowed the progress in metabolic engineering. Sometimes, scientists who discover certain beneficial microbes also get legal protections that restrict others from performing investigative studies on the newly discovered microorganism. In other instances, it is not possible to study the metabolic pathways of some microorganisms because they cannot be cultured in the laboratory for various reasons.

■ ■ ■

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[*See Also* **Vol. 3, Biodegradable Packaging and Products; Vol. 3, Bioremediation; Vol. 2, Genetic Engineering.**]

Multiple Sclerosis Drugs

Description

Multiple sclerosis (MS) is a disease that affects the central nervous system (CNS). MS causes the gradual breakdown of the nerve cell's myelin sheath. Myelin is a fatty coating found on neurons (nerve cells) that protects and aids the brain in instructing the body and mind to respond to stimuli. The name multiple sclerosis refers to the many scars formed on the sheath. MS is a chronic, inflammatory disease, and is classified as an autoimmune disease because it is thought to arise from the body's attack on its own immune system and nervous system.

MS is the most common acquired disease of the nervous system. It affects an estimated one million people worldwide; 350,000 of them are in the United States. MS primarily affects adults between the ages of twenty and forty, and is more common among women than men. MS can affect sensation, vision, muscle strength, and mood, and it results in difficulty with coordination and speech. Although MS in itself is often not a terminal disease (one that causes death), patients suffer from pain and impaired mobility in severe cases.

Although much is known about MS and the damage it does, it is yet unknown what exactly triggers the disease, and there is no complete cure. There are, however, many drug treatments available that may slow the progression of MS, lessen the frequency and severity of symptoms, and overall reduce the disability associated with the disease.

MS drugs have shown to be effective in clinical trials (testing on people) for improving the physical condition of MS patients. In addition, the drugs are able to reduce the number of MS lesions (areas of damage) in the brain and spinal cord. Each drug is used on a regular basis, usually anywhere from once a day to once a week. The drugs are injected, usually by the patient or someone close to the patient.

Man undergoing plasmapheresis treatment for multiple sclerosis. In this treatment, blood is removed from the patient and the harmful agents that attack the nerve cells are filtered out before returning the blood to the body. © *Annie Griffiths Belt/Corbis.*

Scientific Foundations

In 1868, French neurologist Jean-Martin Charcot was the first to classify MS as a distinct disease. In the course of his studies, Charcot identified three signs of MS: dysarthia (problems with speech), ataxia (problems with coordination), and body tremors.

Since that time, the National Multiple Sclerosis Society has divided MS into four types for the purposes of identification and treatment: relapsing-remitting, secondary-progressive, primary-progressive, and progressive relapsing. Relapsing-remitting involves unpredictable relapses and attacks followed by remission (periods of no attacks). When symptoms go away between remission periods, it is called benign MS. It is the second most common type of MS. Secondary-progressive patients first go through a relapsing-remitting phase, which is followed by less severe attacks (but total remission does not occur). It is the most common type of MS.

Primary-progressive involves MS symptoms that never go away; however, they increase and decrease in intensity over time. Progressive-relapsing patients have initial MS symptoms that steadily decrease in intensity, but with sudden and often severe attacks occurring from time to time. Primary-progressive and progressive-relapsing types of MS occur the least often of the four types.

Development

Interferons were the first class of drugs available to treat MS. These drugs block immune proteins, called MHCII (major histocompatibility complex II), which are associated with destroyed myelin in nerve cells. Interferon drugs used for MS include IFN1b (Betaseron®) and IFN1a (Avonex®). Copaxone® (glatiramer acetate, formerly called copolymer-1), is another type of drug. Copaxone is a artificially created molecule that resembles a protein found in myelin.

These three drugs (Avonex, Betaseron, and Copaxone) are commonly referred to as the ABC drugs. All three have been shown to reduce the rate of relapses (recurrence of symptoms of the disease) in persons with MS. These drugs are administered by injection only and have many side effects, including pain and skin injury at the injection site, nausea, vomiting, headaches, and depression. Long-term use of interferons like Avonex and Betaseron may result in the development of antibodies (a protein produced by the body to eliminate foreign substances or fight disease), lessening their effects.

Corticosteroid drugs may also be used as a treatment for MS. Corticosteroids reduce pain by suppressing the immune system's attack on myelin. However, steroids do not improve the long-term course of the disease and will lose effectiveness over time. There is no agreement on the best form of corticosteroid use or dosage for MS.

Tysabri® is the first monoclonal antibody to be produced to treat MS. An antibody is produced by the immune system to help fight disease and viral infection. A monoclonal antibody is spe-

Eureka! There's Gold in MS Drugs

In the last part of nineteenth century, French neurologist Jean-Martin Charcot used gold injections to treat MS because it was shown to be an effective treatment for syphilis, another disease that can affect the nervous system. While this idea may at first seem ridiculous, recent research at Harvard Medical School has shown that gold and other metals, such as platinum, work by stripping bacteria and virus particles from the grasp of a key immune system protein, thus making the protein inactive. The protein MHCII normally holds pieces of invading bacteria and virus to the cell surface. When the cell recognizes that these invaders are present, it starts a normal immune response. In an autoimmune disease, this response goes awry and the body turns on itself causing diseases like type I diabetes, lupus, or rheumatoid arthritis.

cially designed in a laboratory to recognize one specific type of foreign substance. Tysabri is only available by injection and, like other MS drugs, has some side effects, including nausea, headache, abdominal pain, and infection.

MS drugs that are still in development include those that are being currently used for cancer and for lowering cholesterol. The link between these drugs and their method of blocking the progression of MS is being determined. There is still much research being devoted to learning more about MS, finding better treatment options, and, some day, discovering a cure.

Current Issues

Tysabri was initially approved by the Food and Drug Administration (FDA) in November 2004 as a treatment to reduce the frequency of relapsing MS. When the drug is administered, the cells that cause the damage and inflammation to the myelin sheath are bound and prevented from moving from the bloodstream into the brain. Clinical trials showed a 66 percent reduction in the rate of relapses. MRI (magnetic resonance imaging) scans showed that Tysabri prevented scarring of the myelin sheath.

Almost a year later, Tysabri was voluntarily removed from the market by its manufacturers because two people who took the drug developed a progressive disease known as PML. Since then, no new cases of PML have been reported.

After a safety evaluation, and hearing emotional testimonials from people who suffer from MS, the FDA approved Tysabri's return to the market in March 2006, listing certain conditions for

Words to Know

Monoclonal antibody: Antibodies produced from a single cell line that are used in medical testing and, increasingly, in the treatment of some cancers.

Neuron: A nerve cell. Neurons may be either sensory (involving the senses) or motor (related to the motion of the body).

Stimuli: An agent, action, or condition that elicits a response.

Terminal: Causing, ending in, or approaching death; fatal.

the drug's use. Most importantly, Tysabri must be used alone, and not in conjunction with any other medicinal therapy. In addition, the patient must show that they cannot tolerate any of the other MS drugs currently on the market.

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[*See Also* **Vol. 1, Corticosteroids; Vol. 1, Painkillers; Vol. 1, Protein therapies.**]

Nuclear Transfer

Description

Nuclear transfer is a laboratory procedure that removes the nucleus (the central part of the cell that contains its genetic information) of a mature cell and places it into an immature female egg cell. The female cell, whose own nucleus has been removed, is then able to reproduce. The nucleus from the mature cell is called the donor nucleus, and it then directs the cell development and ultimately the expression of basic physical characteristics. Such an artificially made egg cell normally forms an embryo and develops into a living plant or animal.

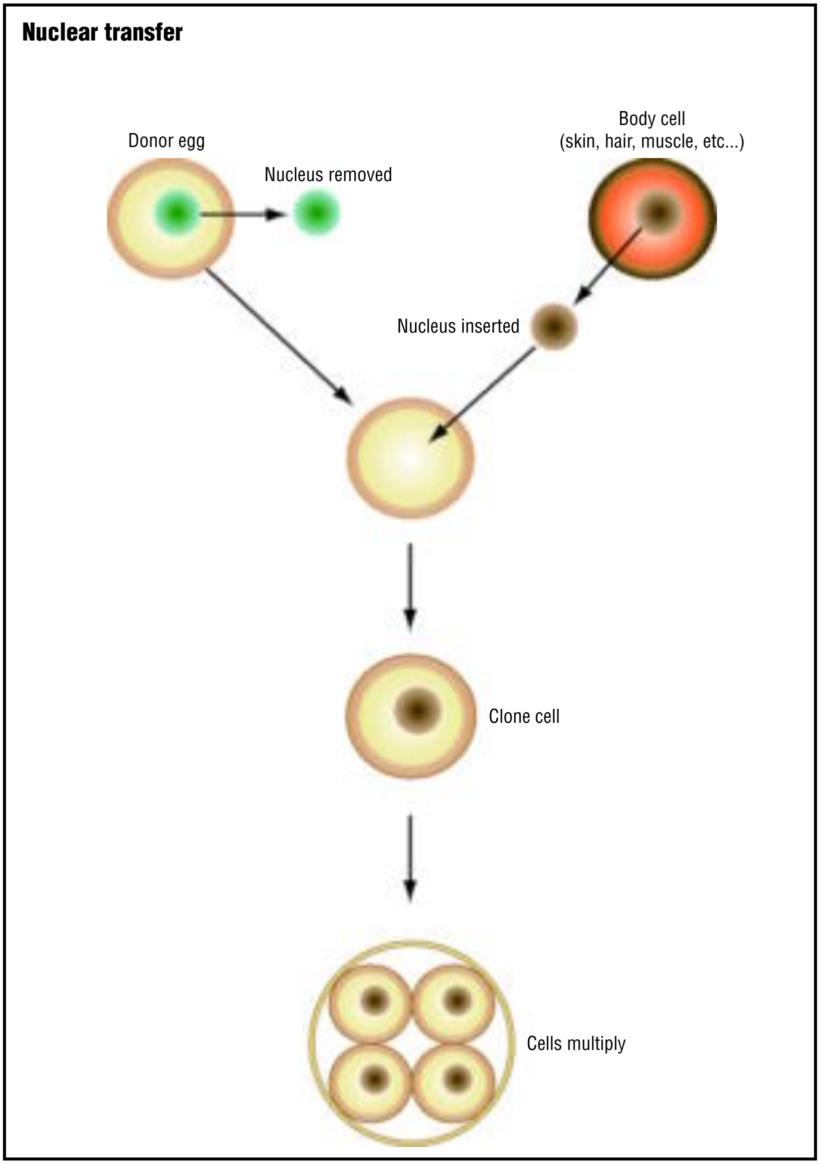
Scientific Foundations

Cloning is defined as creating a genetic copy of a living thing, anywhere from a simple cell to an organism, such as a sheep. The copies (or clones) made with cloning have the same genetic blueprint (gene structure) and, if raised in a similar environment, similar physical characteristics as the original. Cloning uses nuclear transfer techniques and other genetic technologies.

The procedure for nuclear transfer uses a small vacuum to keep the donor cell in place. A thin needle is stuck through the membrane of the cell and inserted into the interior of the cell. The nucleus is then removed through the hollow needle. Later, the needle is inserted into the recipient cell (after its original nucleus has been removed in a similar way) and the donor nucleus is placed inside.

Although cloning might be considered a new technique, and nuclear transfer a new technology, the attempt to alter future generations of plants and animals is not new. Farmers have crossbred (or cloned) plants for thousands of years. They hoped, in many cases, to make new plants that would grow faster and stronger, produce larger

How cells are cloned with the technique of nuclear transfer. When the cloned cells multiply, they become a copy of the donor of the body cell. *Illustration by GGS Inc.*


Nuclear transfer
Donor egg
Nucleus removed
Body cell
(skin, hair, muscle, etc...)
Nucleus inserted
Clone cell
Cells multiply

seeds, or make better tasting fruits. Genetic engineering began in the late twentieth century when scientists modified the genetic material, deoxyribonucleic acid (DNA), of a plant to change its characteristics. Whereas crossbreeding by farmers was only modestly successful, scientists are now able to clone thousands of plants very inexpensively over a short period. The cloning of animals, however, still takes much time, is costly, and results in small groups of plants or animals.

A ‘‘Fantastical’’ Experiment

In 1952, scientists Robert Briggs and Thomas J. King used nuclear transfer to clone frogs. Although they later claimed to be unaware of Hans Spemann’s work their experiment was similar to what Spemann proposed in 1938 as ‘‘a ‘fantastical’ experiment.’’ Briggs and King tried to clone tadpoles using donor nuclei obtained from older cells (differentiated cells) but found that the embryos did not develop or that they developed abnormally and that genetic potential diminished as cells from older and become more specialized (differentiate). In many cases they could not clone organisms from adult cells.

Development

German embryologist Hans Spemann (1869–1941) was the first to propose nuclear transfer. In 1938, Spemann published his experimental conclusions in which he described the use of a slip of hair to divide a fertilized salamander egg into a nucleus and a cytoplasm (the material surrounding the nucleus inside a cell). After the nucleus divided four times—changing into a sixteen-cell embryo—Spemann removed the hair so the nucleus and cytoplasm could join back together. The cell then began to divide again. Spemann tightened the hair again, which caused the cell to divide into two embryos and grow into identical salamanders.

In 1948, American embryologist Robert Briggs (1911–83) began studying the possibility of nuclear transfer (without knowing about Spemann’s earlier research) while performing experiments related to chromosomes (structures within the nucleus that contain DNA) developing within the nucleus. American embryologist Thomas King (1921–2000) helped him with the surgical techniques. They used a North American leopard frog because its eggs are larger than most other animals’ eggs. Using a tiny needle, King applied suction to a single cell from an embryo containing thousands of cells. When the cell was opened, the nucleus was removed and inserted into an egg whose nucleus had been earlier removed. After improving their technique, Briggs and King published their findings in 1952. Other scientists tried similar experiments after reading their article.

Current Issues

Nuclear transfer has the potential to reproduce genetically altered animals that can produce drugs to fight diseases like Alzeheimer’s and Parkinson’s. Animals cloned as a result of nuclear transfer might provide organs to transplant into humans needing new organs.

Words to Know

Deoxyribonucleic acid (DNA): The double-helix shaped molecule that serves as the carrier of genetic information for humans and most organisms.

Embryo: A stage in development after fertilization.

Embryologist: A scientist who studies embryos and their development.

Cloning animals may help endangered species avoid extinction, or even bring back extinct animals, similar to what happened in the movie *Jurassic Park* (1993). Many people are in favor of cloning for its medical and other benefits. Other people are against cloning because of ethical and religious reasons.

Critics of animal cloning say that cloned animals, including humans, could be born with serious defects. They argue that some of the world's past dictators tried to breed out characteristics in people that they felt were undesirable. Some religious groups argue that cloning goes against their beliefs.

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[*See Also* **Vol. 2, Animal Cloning; Vol. 1, Bioethics; Vol. 2, Biotech in the Dairy Industry; Vol. 1, Human Cloning; Vol. 2, Genetically Engineered Animals.**]

Organ Transplants

Description

An organ transplant is a surgical procedure to put a healthy body part (organ) into a person whose organ no longer works. Organs that can be transplanted include the heart, kidneys, lungs, pancreas, and liver.

According to the United States Division of Transplantation, about seventy-four people get an organ transplant every day. However, many people die waiting for transplants because there are not enough donated organs. In April 2006, more than 91,000 people in the United States were waiting for an organ transplant.

Hearts and lungs can only be taken from a person who has just died. This has to be done right away because organs died very quickly after death. A person who is legally dead is often kept on special machines to keep the body functioning until the organ can be removed.

Kidneys and livers may be donated by a person who is alive, since the liver grows back and most people are born with two kidneys.

Scientific Foundations

One of the biggest problems facing transplant patients is rejection. Rejection means the body looks at the new organ as an invader and attacks it. In 1983, the drug cyclosporine was approved to help prevent rejection. The drug's approval lead to a big increase in the number of organ transplant procedures.

In 1999, the National Institutes of Health (NIH) Clinical Organ Transplant Program was formed to develop and test new ways of preventing rejection. The development of new transplantation techniques and better anti-rejection drugs in recent years has helped people with organ transplants live longer. The number of heart- and lung-transplant patients living three years or more after

This twelve-year-old boy is playing with his old diseased heart, after his successful heart transplant surgery. *AP/ Wide World Photos.*

their surgery continues to rise. The percentage of patients who lived for at least three years jumped from 55 percent between 1988 and 1994 to 64 percent between 2000 and 2003.

Scientists have been looking into the causes of death following transplants. A study found that patients who get a severe lung injury called primary graft dysfunction after a lung transplant are much more likely to die within the first month than those who did not have the problem. Researchers are working on new ways to better predict and treat transplant-related lung problems.

Tracking Donors and Patients

People who need a transplant must join the Organ Procurement and Transplantation Network (OPTN), a national program run by the United Network for Organ Sharing (UNOS). UNOS keeps a database of all patients waiting for transplants. The organization also determines who gets which organs. A national computerized system helps match donated organs to a person who needs one. The transplanted organ must work with the person's blood type. Other considerations are organ size, how badly the person needs a transplant, how long they have waited for it, and the patient's location.

Development

Transplants date back thousands of years. The Chinese were believed to have tried transplanting a heart as early as the second century BCE. Roman myths suggest that people tried transplanting a leg from one man to another. In 1902, Hungarian surgeon Emerich Ullmann (1861–1937) performed the first successful kidney transplant in a dog.

The first human-to-human kidney transplant took place in the late 1950s, when surgeons at a hospital in Boston, Massachusetts successfully took a kidney from one man and put it inside his twin brother, who was dying from kidney failure. The lead surgeon, American-born Joseph Murray (1919–), won the Nobel Prize in Physiology or Medicine in 1990 for his work.

Soon, physicians tried to transplant other organs. After four unsuccessful years, the first successful human liver transplant took place in 1963 at the University of Colorado. Meanwhile, South African physician Christiaan Bernard (1922–2001) completed the world's first heart transplant. The patient lived for eighteen days. The first successful heart transplant in the United States took place a year later. Houston, Texas physician Denton Cooley transplanted a heart into a forty-seven-year-old man during a procedure at St. Luke's Episcopal Hospital. The patient lived for 204 days.

The same year, the United States passed a law (Uniform Anatomical Gift Act) that established a donor card. People who wished to donate their organs after death carried the card with them. The law also allowed families to say yes or no to organ donation.

In 1984, the National Organ Transplant Act took effect. This law made the sale of human organs illegal. It also set up a nationwide program called the Organ Procurement and Transplantation Network (OPTN) to take in and distribute donated organs.

Words to Know

Immune system: A system in the human body that fights off foreign substances, cells, and tissues in an effort to protect a person from disease.

Immunosuppressive drugs: Medicines that turn off the body's defense (immune) system. They are used to fight organ transplant rejection.

Organ Procurement and Transplantation Network (OPTN): A program that promotes organ donation and oversees the national distribution of organ transplants.

Primary graft dysfunction: A severe lung injury that occurs in some lung transplant patients.

Rejection: An event that occurs when the body's defense (immune) system attacks a transplanted organ.

United Network for Organ Sharing (UNOS): A Richmond, Virginia company that runs the Organ Procurement and Transplantation Network.

Current Issues

Every day, someone who is waiting for an organ transplant dies. The shortage of donated organs is a big concern. The demand for organs is simply larger than the supply. People on the waiting list for organs do not know how long they will wait to receive one. Long wait times not only cause a person's health to get worse, they also create more expensive medical costs because the person must often stay in a hospital until a transplant donor is found.

Donated organs must be matched as closely as possible to the patient so that the risk of rejection is low. However, even with a good match, the body still thinks of the new organ as a foreign substance. Organ transplant patients must take medicines that turn off the body's defense (immune) system. Such medicines are called immunosuppressive drugs. Most transplant patients must take some type of medicine for the rest of their life.

Immunosuppressive drugs can have dangerous consequences. Because they suppress the immune system, the body has a hard time fighting off even the simplest of infections. Patients who take these medicines also have a higher risk of certain cancers. Side effects of immunosuppressive drugs include high blood pressure, high cholesterol, and an increased risk of diabetes.

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[*See Also* **Vol. 1, Anti-Rejection Drugs.**]

TYLENOL
3
CODEINE

Tablet of Tylenol #3 with codeine. © *Thomson Micromedex.*

Painkillers

Description

Painkillers, also called analgesics, are medicines that help relieve pain. There are many different types of painkillers. The most common types of painkillers include anti-inflammatory drugs, non-narcotics, and opioids (narcotics).

Anti-inflammatory drugs reduce swelling and soreness. They are often used to treat muscle, bone, and joint pain. People with osteoarthritis or arthritis (diseases that cause joint pain and bone changes) sometimes take anti-inflammatory drugs. Anti-inflammatory painkillers are classified according to whether or not they contain a steroid, a powerful chemical that reduces swelling. Those without steroids, such as aspirin and ibuprofen, are called non-steroidal anti-inflammatory drugs (NSAIDs).

Some NSAIDs (like aspirin) are available over-the-counter (without a doctor's prescription). Stronger NSAIDs require a prescription. They include naproxen, ketoprofen, and diclofenac.

The most common non-narcotic painkiller is acetaminophen (Tylenol®). It works on mild-to-moderate pain and costs less than other pain medicines. Acetaminophen is the main ingredient in hundreds of different painkillers. It can be bought in grocery stores and pharmacies without a prescription. Acteaminophen is the most popular type of painkiller used in hospitals.

Opioids are the strongest painkillers. They are listed as narcotics because act quickly and can be addicting. These drugs are usually given to people with post-surgical pain, cancer, long-term (chronic) back pain, and severe headaches. Morphine is the strongest opioid painkiller. Codeine is a weaker type, but still powerful. Acetaminophen is commonly combined with codeine (Tylenol #3). Opioid pain killers can only be purchased with a prescription.

Scientific Foundations

Painkillers relieve pain through differing biochemical actions. Aspirin and other NSAIDs work to stop the body from producing a chemical called prostaglandin. Along with other functions, prostaglandin causes muscles to tighten and blood vessels to constrict, often leading to pain and swelling. By blocking prostaglandin, muscles relax and blood vessels dilate (widen), reducing pain and swelling. Although the exact action of opioid pain relievers is not known, scientists assume they act directly on pain receptors (nerve cells) in the central nervous system.

Development

Opioid medicines have been used for thousands of years. They date back to 300 BCE, when people learned that the seeds of the poppy flower, made into a powder and named opium, gave a feeling of well-being to those who smoked it. In 1803, German scientist Friedrich Wilhelm Sertürner (1783–1841) identified the powerful pain-killing chemical in the opium powder as morphine. Many nineteenth century medicines were based on a mixture containing alcohol and opium. This product was called “tincture of opium,” or laudanum.

The drug manufacturer E. Merck & Company of Darmstadt, Germany, began making morphine in 1827. Today, researchers use the sap of the poppy flower to create synthetic (not from a natural source, such as a plant) drugs such as oxycodone that copy opium’s pain-relieving effect.

Aspirin was the first type of painkiller sold in the United States. The ancient Romans used a raw form of aspirin from the willow tree to cure aches and pain. In the late 1800s, a scientist at Friedrich Bayer

New Uses for Painkillers

Scientists are also investigating different ways to use existing painkillers. For example, aspirin and other NSAIDs may be able to prevent cancer of the colon, stomach, breast, and lung. An early study involving people with severe memory and reasoning impairment (dementia) found that acetaminophen helped make them more alert and active. Other research suggests that certain NSAIDS may slow down the progress of Alzheimer's disease, a severe brain disease that causes dementia and behavior problems, usually in older people.

& Company in Germany developed a synthetic version of aspirin called acetylsalicylic acid, and found that it helped relieve arthritis pain.

In 1955, the Johnson & Johnson company McNeil Consumer Products introduced liquid acetaminophen for children. The drug was the first aspirin-free pain medicine.

Low doses of ibuprofen, the most popular type of NSAID, became available without a prescription in the 1980s. There are many brands of ibuprofen, including Advil®, Motrin®, and Nuprin®.

COX-2 inhibitors are the newest type of NSAIDs. These drugs block a different pain-causing chemical than older anti-inflammatory drugs. Researchers developed these drugs because existing NSAIDs sometimes caused stomach problems such as ulcers. COX-2s reduced the risk of stomach troubles and were proclaimed to be valuable pain relievers, especially for people with a history of stomach problems. Three COX-2 drugs were developed: celecoxib (Celebrex®), rofecoxib (Vioxx®), and valdecoxib (Bextra®). However, researchers soon learned that some patients taking COX-2s had a higher risk of heart attacks and strokes. The U.S. Food and Drug Administration (FDA) recommended drug manufacturers stop selling rofecoxib and valdecoxib, and in 2005, they stopped being sold.

Current Issues

Researchers continue to look for safer, more effective painkillers. Significant progress has been made in understanding how a person actually feels pain. This knowledge is being used to develop new ways to safely block pain signals. One new non-narcotic drug, ziconotide, derived from a natural chemical produced by snails, works by blocking particular minerals in the nerve cell that transmit

Words to Know

Analgesic: A compound that relieves pain without loss of consciousness.

Arthritis: Inflammation of the joints.

Narcotic: A drug that depresses the central nervous system and is usually addictive.

Opium: A natural product of the opium poppy, *Papaver somniferum*. Cutting the immature pods of the plant allows a milky liquid to seep out and be collected. Air-dried, this is crude opium.

Steroid: A group of organic compounds that belong to the lipid family and that include many important biochemical compounds including the sex hormones, certain vitamins, and cholesterol.

pain signals to the brain. Ziconitide is delivered directly to the spinal fluid and is reserved for severe or chronic pain. Another new drug, pregabalin, targets the specific nerve pain caused by complications from certain diseases, such as diabetes or shingles.

Painkillers are powerful drugs and may cause side effects. Considerable concern has been raised over the safety of all NSAIDs, especially COX-2 inhibitors. Medical evidence found that people who regularly take large doses of such painkillers have an increased risk of heart attack, stroke, and bleeding in the stomach.

On April 7, 2005, the FDA ordered drug manufacturers to add a warning label to all NSAIDs. The label, called a black-box warning, states that the drugs could increase a person's risk of serious, possibly life-threatening events, particularly heart attacks, strokes, and stomach bleeding. The agency also warned that people who recently had heart surgery should not take some types of NSAIDs.

The bad news regarding COX-2s and NSAIDs resulted in increased sales for the makers of acetaminophen products. Acetaminophen is considered one of the safest painkillers. It does not cause the stomach problems often seen with NSAIDs. However, large amounts of the drug can cause liver disease. A study published in 2005 stated that daily use of the drug could increase blood pressure in women.

Among the most effective but problematic painkillers are the opioid narcotic drugs. While persons with persistent or severe pain can benefit from them, these drugs are physically addictive (causing users to become dependent on them) and commonly abused. Large amounts of opioid drugs can prevent a person from coughing, and in severe cases, cause breathing to stop. Other side effects include constipation, nausea, and vomiting. Those who take opioid drugs for long periods of time for medical reasons must stop taking them gradually to avoid withdrawal symptoms (negative reactions to not having the drug). While the law requires stringent quality and supply controls for opioids used in medical settings, they are frequently sold illegally. Narcotics sold on the street, including morphine and heroin, can be contaminated with dangerous ingredients.

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[*See Also* **Vol. 1, Aspirin.**]

Paternity Testing

Description

The word paternity means to be someone's father. Paternity testing is a way to know with great certainty whether or not a man is a child's father by comparing their genetic material.

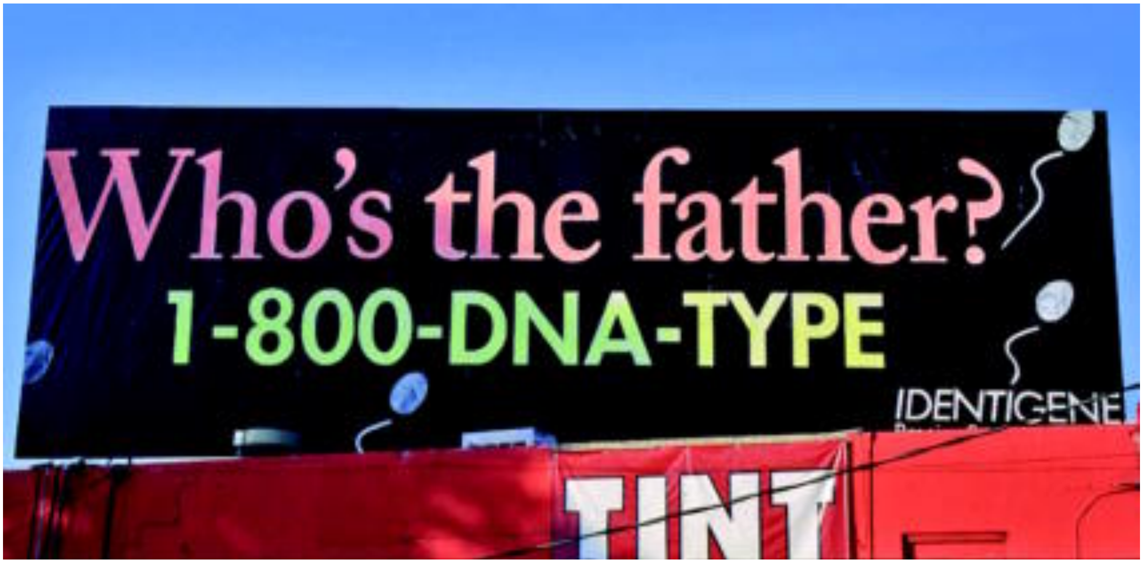
Paternity testing is used, for example, if the mother has had intercourse with more than one man at around the same time. The mother may need to prove the father's identity before asking for money to support the child or for the child's inheritance money. It can also be done for matters of immigration, child custody (the legal right of a parent to care for and make decisions regarding their child), or adoption.

Scientific Foundations

Deoxyribonucleic acid (DNA) is the genetic material that is present in each cell of the human body. It is unique to each person and determines traits such as hair color, eye color, and height. DNA is made up of a sequence of bases—adenine (A), cytosine (C), guanine (G), and thymine (T). The order of these bases determines the individual's traits. DNA is tightly packed into structures called chromosomes.

With the exception of identical twins, every person's DNA is slightly different. A few differences in the sequence of bases are what make one person look and act different from another person. The closest DNA matches are between family members, since each child inherits DNA from his or her mother and father.

Sperm and egg cells each carry twenty-three chromosomes. During reproduction, when the sperm fertilizes the egg, the chromosomes from the father and mother combine. This gives the child a full set of forty-six chromosomes—half from the father, and half from the mother.



Billboard in Texas advertising paternity testing services. *B. Daemmrich/The Image Works.*

Because a child receives half of his or her DNA from the father, it is possible to test to find out whether a man is the child's biological father. Scientists can take blood or other tissue from the child and the supposed father and compare the DNA to see if they match.

Development

A German scientist named Friedrich Miescher discovered the building blocks of DNA in 1869, but it took more than one hundred years for scientists to understand how to use DNA to identify a person. In 1985, a British geneticist (a scientist who studies genes) named Alec Jeffreys discovered that certain DNA sequences repeated over and over again. He also found that the repeated sections could differ slightly from one person to the next. Jeffreys discovered a way to identify DNA variations between people. His discovery paved the way for DNA fingerprinting in crime investigations, as well as for paternity testing.

A paternity test can be done while the baby is still in the mother's womb, or after the child has been born. A small sample of fluid or tissue is taken from the child, and a sample is taken from the man who is believed to be the father. Although paternity tests are usually done in a laboratory, there are tests that take a swab of tissue from the father and child's cheek that can be done at home.

To confirm paternity, scientists look for certain sections of the child's DNA that show variations. At each chromosome are two fragments of DNA, one that the child inherited from the father, and one that the child inherited from the mother. These are called alleles.

Paternity Tests Before Birth

A child's paternity can be tested while he or she is still in the womb. The procedures used to take a DNA sample during a woman's pregnancy are called chorionic villus sampling and amniocentesis. In chorionic villus sampling, small pieces of tissue that are attached to the mother's uterus (the hollow organ in a woman's body that houses the growing fetus) are removed. These pieces of tissue contain the baby's genetic material. Amniocentesis is done by passing a needle through the mother's stomach. A small sample of amniotic fluid (the fluid around the developing fetus) is removed. The fluid has cells in it that contain the baby's DNA. Samples from both of these tests are taken to a lab for DNA testing. A comparison to the father's DNA can then be done.

First, scientists remove DNA from tissue samples taken from the mother, the child, and the potential father. They use a special type of molecular scissors called restriction enzymes to cut the DNA into fragments. The cut fragments are separated by length using a special gel. Then the fragments are placed on a type of nylon film. Special radioactive (giving off high-energy rays) strands of DNA called probes are also placed on the film. These probes seek out and stick to specific base sequences. When the sheet containing the probes is exposed to an x ray, the probes form a visible pattern.

Scientists take DNA from the mother and compare the pattern with that of the child's DNA. Once they have identified the fragment from the mother, they know that the other fragment must be from the father. Then they use DNA taken from the man who is thought to be the father, to see if it matches that fragment. If it does match, the man is almost certainly the father.

Current Issues

DNA testing is very accurate. It can tell whether a man is a child's father with about 99.9 percent certainty. It can tell with 100 percent certainty whether a man is not the father.

There are certain ethical (having to do with morality, or what is perceived as being the right thing to do) issues surrounding paternity testing, though. A father might try to use it to avoid having to pay child support, for example. A man might want a child tested if he thinks his wife has been unfaithful to him. Or a man who left his family years ago might come back home and request a paternity test to prove that he is the father of the child he left behind. There

Words to Know

Allele: Any of two or more alternative forms of a gene that occupy the same location on a chromosome.

Amniocentesis: A method of detecting genetic abnormalities in a fetus; in this procedure, amniotic fluid is sampled through a needle placed in the uterus; fetal cells in the amniotic fluid are then analyzed for genetic defects.

Amniotic fluid: The fluid that surrounds the developing fetus in the womb.

Chorionic villus sampling: Testing a sample of cells from the tissue surrounding the embryo. It can be used to determine a child's paternity before he or she is born.

Chromosome: A thread-shaped structure that carries genetic information in cells.

Custody: The legal right of a parent to care for and make decisions regarding their child.

Deoxyribonucleic acid (DNA): The double-helix shaped molecule that serves as the carrier of genetic information for humans and most organisms.

Ethical: Having to do with morality, or what is perceived as being the right thing to do.

Geneticist: A scientist who studies genes.

Paternity: The genetic father of an offspring.

Radioactive: The production of high-energy rays as a result of changes in the atomic structure of matter.

Restriction enzyme: A special type of protein that can recognize and cut DNA at certain sequences of bases to help scientists separate out a specific gene.

is concern that having a paternity test in these cases could emotionally hurt the children involved, or that it could be done without the mother's consent.

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[*See Also* **Vol. 1, Bioethics; Vol. 1, DNA Fingerprinting; Vol. 1, DNA Sequencing; Vol. 1, Forensic DNA Testing; Vol. 3, Polymerase Chain Reaction.**]

Penicillins

Description

Penicillins are prescription medicines used to treat infections that are caused by bacteria (a one-celled germ that can cause disease). Penicillin is a type of antibiotic, a drug that kills bacteria. Penicillin does not kill viruses, so it does not work for a cold or the flu.

Scientific Foundations

There are many different types of penicillin. They are grouped into two categories: natural or human-made. Natural penicillin is called biosynthetic penicillin. It is produced directly from mold. Penicillin type G (benzylpenicillin) is the only natural penicillin used today. This type of penicillin must be given with a needle (injection).

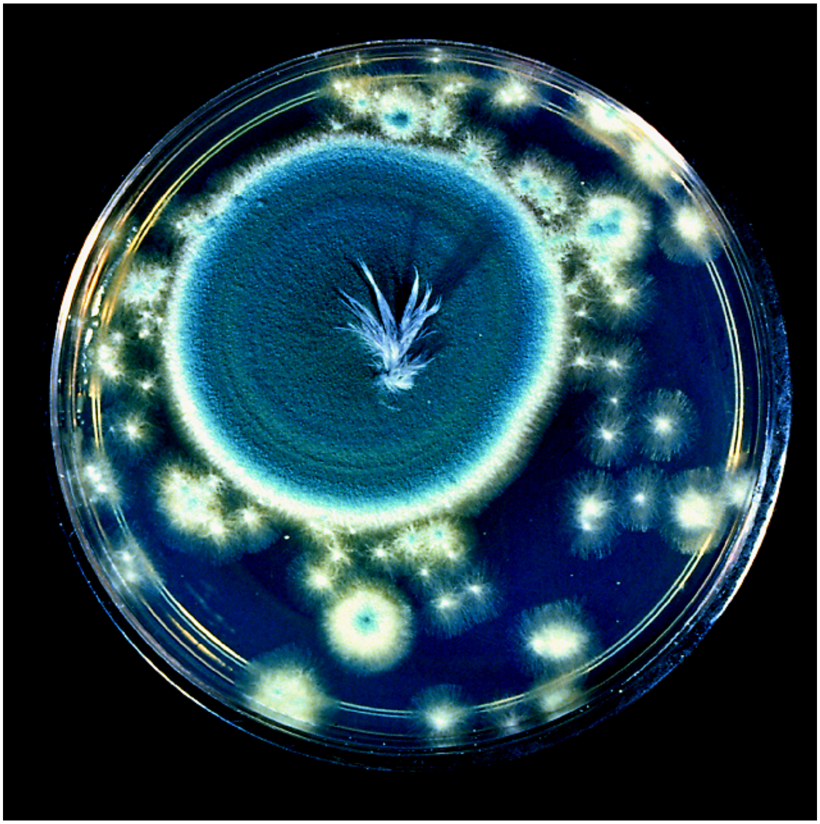
Penicillin created in the laboratory is called semi-synthetic penicillin. Scientists create this type of medicine by slightly changing the structure of natural penicillin. Popular types of human-made penicillin include penicillin V, ampicillin, and amoxicillin.

Penicillin fights many diseases, but not all. Some germs cannot be killed with penicillin, so researchers have been trying to come up with newer types of antibiotics. Some physicians say penicillin should not be used to treat children who have strep throat, because newer, less expensive drugs called cephalosporins work better.

Many people are allergic to penicillin. Scientists are working on a skin test that can be used to figure out who might have a bad reaction to the drug.

Development

Scottish scientist Alexander Fleming (1881–1955) accidentally discovered penicillin in 1928 while working at St. Mary's Hospital



A laboratory culture dish growing penicillin mold. *P. Barber/Custom Medical Photo Stock, Inc.*

in London. He covered a plate with bacteria, but then left it at room temperature for a long time. When he looked at the plate later, he noticed a green mold growing on the plate. The bacteria near the mold were dying. The mold was later identified as *Penicillium notatum*, or penicillin for short. Under a microscope, the penicillin had the shape of a pencil.

Fleming experimented with the penicillin for a while. He discovered the penicillin mold was not dangerous. He believed it could fight some illnesses, but he could not get it into a form that still worked when given to humans. In 1929, he published a paper in the *British Journal of Experimental Pathology* on his discovery of penicillin and its potential uses, but the scientific community did not seem interested. As a result, penicillin's disease-fighting ability remained unexplored for more than ten more years. During World War II (1939–1945), German biochemist Ernst Boris Chain (1906–1970) and Australian pathologist Howard Walter Florey (1898–1968) found a way to turn the raw penicillin into a brown powder that still killed bacteria even

Penicillin Saves Nurse First

In March 1942, young nurse Anne Sheafe Miller lay near death in a Connecticut hospital with a temperature near 107 degrees Fahrenheit (42 degrees Celcius) caused by a streptococcal infection. After trying everything available to save her life, including sulfa drugs, blood transfusions, and surgery, doctors gave Nurse Miller an injection of a small amount of an experimental drug, penicillin. Overnight, Miller's fever decreased, and by the next day, she was alert and eating meals. Miller became the first person whose life was saved by penicillin, and afterward, American pharmaceutical companies quickly geared up to mass-produce the drug, first for soldiers overseas, then for the public at large. Anne Miller lived until she was ninety years old.

after a few days. They gave it to mice, and found it made bacteria infections go away. Soon, the drug was being produced in a large quantity, and used to treat people who were injured during the war. In 1945, Fleming, Florey, and Chain received the Nobel Prize in Physiology or Medicine for their discoveries related to penicillin.

Chain and Florey's work also revealed that there were several different forms of penicillin. All of them worked in a similar fashion but, under a microscope, each looked slightly different. Medical persons gave a form of the drug called penicillin V to World War II soldiers who had infected cuts (wounds). This was a considerable achievement. Before the discovery of penicillin, minor wounds turned into serious bacteria infections that eventually caused death. The use of penicillin during the war helped save many lives. By the time the war was over, companies in the United States were producing 650 billion units of penicillin each month.

Shortly after the war, Oxford chemist Dorothy Crowfoot Hodgkin (1910–1994) revealed the complex structure of penicillin. Her discovery allowed scientists to come up with ways to make artificial (synthetic) forms of the drug.

Current Issues

Penicillin was once considered a wonder drug. However, it is not used as often as it was in the past because of widespread antibiotic resistance. Antibiotic resistance is major public health threat in which bacteria cannot be killed with antibiotic medicines. Just a few years after natural penicillin was being made and used in large supply, scientists realized that it could no longer kill certain germs. Such resistance makes bad bacteria become stronger, leading to "super germs." This can make an infection become much worse. For example, ear infections caused by

Words to Know

Anaphylactic shock: A violent, sometimes fatal, response to an allergen after initial contact.

Antibiotic: A compound produced by a microorganism that kills other microorganisms or retards their growth. Genes for antibiotic resistance are used as markers to indicate that successful gene transfer has occurred.

bacteria are difficult to successfully treat with antibiotic drugs. In such cases, treatment is a guessing game. A physician will need to give the patient different antibiotics, until one works.

The first type of bacteria to show resistance to penicillin was *Staphylococcus aureus*. This type of bacteria can lead to pneumonia, a serious disease that causes swelling of the lungs.

Antibiotic resistance can occur in people who take penicillins and other antibiotics on a regular or repeated basis. People who use antibiotics when it is not necessary or who do not take all of their antibiotic medicine have a higher risk for resistance.

Penicillin can cause stomach aches and diarrhea. Women who take penicillin sometimes develop a yeast infection in their vaginas. This common condition causes extreme itchiness.

Many people are allergic to drugs made with penicillin. If a person who is allergic to penicillin is given such a drug, they can have a life-threatening condition called anaphylactic shock, which causes breathing problems, swelling, itchy bumps (hives), and a sudden, severe drop in blood pressure.

Penicillin can interact with a number of medications, including blood thinners, thyroid drugs, blood pressure drugs, birth control pills, and other antibiotics.

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[*See Also* **Vol. 1, Antibiotics, Biosynthesized; Vol. 3, Antimicrobial Soaps.**]

Pharmacogenetics

Description

A person's response to medication often depends on their genes. Pharmacogenetics is the study of how people with certain inherited genes will react to specific medications. By learning how people with certain genes respond to a particular drug, doctors can know in advance what kind of reaction a patient with a similar genetic makeup might have.

Medications are usually one-size-fits-all. Although today's medicines can treat disease very effectively, sometimes doctors have to try many drugs until they find one that works for their patient. Many drugs cause side effects; some can even be life threatening. One study found that reactions to medications kill about 100,000 people and send more than two million people to the hospital each year.

Scientific Foundations

Deoxyribonucleic acid (DNA) is the genetic material in each cell of the human body. It is made up of a sequence of chemical bases—adenine (A), cytosine (C), guanine (G), and thymine (T). The order of these bases tells the body's cell how to make proteins, the main components of living things. Which proteins are produced determines an individual's traits. Proteins direct all of the functions of the body, from hair and eye color, to the likelihood of getting certain diseases.

When drugs enter the body, they come in contact with proteins. How the proteins and drugs interact determines whether a person will get better, stay the same, or have a harmful reaction to the drug. That interaction also determines how the person's body will break down and remove the drugs. People produce slightly different

Chemist using an oxygen meter to perform a bioassay test. Bioassays are sometimes used to measure how well a drug is working in a biological system. © *Bob Rowan; Progressive Image/ Corbis.*

proteins, so one person may react to the same medication differently than another person.

Development

Since the 1950s scientists have been able to recognize that inherited differences in certain proteins could affect the way people respond to medications. For decades, doctors have been able to test a person's blood to find out if they are a match for an organ transplant or blood transfusion (a procedure to replace blood lost during an accident, illness, or surgery). The next step was to find out how to genetically test people to learn in advance how they will react to medications. To do that, scientists needed to look closely at people's DNA.

Scientists were first able to find the order of chemical bases in a section of DNA (called sequencing) in the 1970s. Identifying a sequence for a specific protein is difficult considering there are three billion base pairs in the human genome (all of the genes in a human being).

By the end of the 1990s, improvements in technology allowed scientists to automate much of the gene-sequencing process. In 2003, scientists of the Human Genome Project announced that they had

Pharmacogenetics Versus Pharmacogenomics

The words pharmacogenetics and pharmacogenomics sound almost exactly the same, but their meanings are slightly different. Pharmacogenetics is the study of genetic variations that affect the way a person responds to a certain medication. Pharmacogenomics, on the other hand, looks at genetic variations in groups of people that make them more likely to develop a disease, or respond to medications in a certain way.

sequenced all of the 20,000–25,000 genes in the human body. This made it possible to identify sections of DNA that code for certain proteins. Their discovery paved the way for the science of pharmacogenetics.

The Human Genome Project helped identify the tiny DNA changes that make one person different from another. Humans are almost identical genetically, but have tiny variations in their DNA called single nucleotide polymorphisms, or SNPs (pronounced "snips"). SNPs are changes to a single nucleotide in the DNA sequence. An example of a SNP would be a change in a sequence of DNA from ATGAGA to ATGACA. This very slight change can affect whether a person develops a disease or reacts to a certain drug.

SNPs occur every 100 to 300 bases along the three billion bases of the human genome. Most SNPs are outside of the coding area, which means they do not code for proteins. The SNPs that lie in a coding sequence are important to scientists because they can change the function of a protein.

SNPs are identified by taking a sample of DNA from the blood or tissue of several different people. The DNA is then sequenced to determine the order of base pairs in each segment. A single gene can contain several million bases, so scientists have to use special chemicals to cut them into fragments. A gel is used to separate the DNA fragments by their sequence (for example, all fragments ending in A, all fragments ending in C, etc.). Scientists then compare the sections to find SNPs. This method used to be done by hand, which took a long time. By the 1990s, computers were able to do the sequencing work much faster.

Current Issues

Pharmacogenetics, or personalized medicine, has the potential to save both money and lives. It could, for example, be used to screen potential study participants for clinical trials of a new drug. This

Words to Know

Deoxyribonucleic acid (DNA): The double-helix shaped molecule that serves as the carrier of genetic information for humans and most organisms.

Genome: A complete set of the DNA for a species.

Pharmacogenetics: The study of how a person’s genetic makeup affects his or her response to medications.

Pharmacogenomics: The study of how human genetic variations affect responses to medications.

Sequencing: Finding the order of chemical bases in a section of DNA.

Single nucleotide polymorphisms: A change to a single nucleotide (A, C, T, or G) in a DNA sequence.

Transfusion: A technique used to replace blood lost during an accident, illness, or surgery.

would help ensure that anyone who might have a reaction to a drug is not included in the trial. This screening process would make trials smaller and less expensive, and could save consumers money on medications. Pharmacogenetics could also help prevent dangerous drug reactions by knowing in advance which people may have a reaction to a certain drug.

Despite the promise of pharmacogenetics, there are several hurdles scientists have to overcome. First, they will need to look at millions of SNPs to know which ones are involved in certain drug responses. Second, even if they know that some people will have a reaction to a kind of medicine, there may not be an alternate drug available to give those people. Lastly, drug companies may not want to spend the research money to develop drugs that will only work on a small number of people.

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[*See Also* **Vol. 1, Antibiotics, Biosynthesized; Vol. 1, Anti-Rejection Drugs; Vol. 1, Blood Transfusions; Vol. 1, DNA Sequencing; Vol. 1, DNA Vaccines; Vol. 1, Organ Transplants.**]

Protein Therapies

Description

Protein therapy refers to a medical treatment that involves the insertion of specific proteins into cells or areas surrounding cells, in order to stimulate or block biological reactions. Proteins are large molecules that are the main components of living cells. Protein therapy is temporary, since a protein does not persist indefinitely, but is degraded over time.

The potential of protein therapy has been demonstrated for the relief of damage caused by autoimmune reactions—where the immune system reacts against the body's own organs and tissues—and the uncontrolled growth of cancer cells, as two examples.

Scientific Foundations

The basis of protein therapy is the use of specific proteins as either triggers of chemical reactions in cells, or to block other proteins that themselves can act as the trigger. The addition of a protein can also stimulate cell signals that, in turn, drive other reactions.

Protein therapy is still in its infancy, but has already demonstrated great potential in adjusting the reaction of the immune system. Normally, the immune system attacks anything that is foreign in the body. This can be quite valuable when the body is invaded by a bacteria or virus that causes an illness. However, an immune response can be unhealthy if it is directed at a person's own tissues and organs. Autoimmunity, as this abnormal reaction is called, is the basis of a number of diseases, including rheumatoid (ROO-muh-toid) arthritis and systemic lupus erythematosus (pronounced LOO-puhs er-uh-THEM-uh-toe-suhs). Protein therapy can be used to block the chemical reactions that cause autoimmune reactions.

Protein Therapy May Spur Drug Development

Any drug that is intended for human use must meet rigorous criteria to establish its effectiveness and safety. This involves testing the drug on humans, which always carries some risk. Some clinical trials of gene therapies have been disastrous, since the dose of the drug could not be rapidly adjusted. Protein therapy may help alleviate this problem.

Proteins are naturally degraded in the body. Because the therapeutic protein must be given to a patient regularly, the amount of the protein can be quickly changed. If signs of trouble are detected, the protein concentration can be lowered. Conversely, if no positive effects are apparent, the protein dose can be increased. Regulation of the protein level can be accomplished with a few hours. This ability to fine-tune the dose is making protein therapy an attractive strategy in the clinical evaluation of treatments for immune-related diseases, neurological disorders, and infectious diseases.

Protein therapy has also shown promise in directing the development of stem cells—special cells that have the potential to develop into virtually any type of mature body cell. The ability to precisely tailor the development of stem cells could allow these cells to be used to regenerate body tissues.

Protein therapy differs from gene therapy. In gene therapy, the gene that codes for the creation of the therapeutic protein is supplied, and the action of this gene within the body subsequently produces the desired protein. Supplying the protein directly is time saving, since the protein does not have to be produced by cells in the body. On the other hand, the proteins supplied by protein therapies need to be administered regularly, because proteins normally break down over time.

Development

One application of protein therapy is in slowing the process of programmed cell self-destruction, known as apoptosis. While useful in maintaining a turnover of cells in the body, excessive or premature apoptosis can be harmful, as in the destruction of insulin-producing cells in the pancreas that underlies diabetes. The introduction of proteins that protect cells has successfully blocked pancreatic cell apoptosis in laboratory studies. Reduced apoptosis also would prolong the life of cells intended for transplantation, which would allow patients more time to travel to a transplant center.

Words to Know

Apoptosis: Programmed cell death in which a controlled sequence of events (or program) leads to the elimination of cells without releasing harmful substances into the surrounding area. Many types of cell damage can trigger apoptosis, and it also occurs normally during development.

Autoimmune disorder: Disorders that are caused by misdirected immune response in which lymphocytes mount an attack against normal body cells.

Immune system: A system in the human body that fights off foreign substances, cells, and tissues in an effort to protect a person from disease.

Liposome: A sphere composed of lipid.

Protein: Complex molecules that cells use to form most of the structures and control chemical reactions within a cell.

Paradoxically, another protein therapy strategy seeks to trigger even greater apoptosis. Researchers have demonstrated that by supplying an artificial version of part of a protein called p53—which functions to suppress cancer tumors by increasing the amount of cell apoptosis that occurs—the destruction of cancer cells can be boosted.

Another potential application for protein therapy is in the relief of rheumatoid arthritis. Researchers have successfully eased the painful symptoms of the disease in volunteers by supplying a therapeutic protein in pill form. The supplied protein blocks the action of another protein, and thus slows the overactive immune response that occurs with that disease.

Current Issues

Protein therapy is an area at the cutting edge of research. The potential of the strategy is already apparent in the regulation of autoimmune responses and the regulation of apoptosis in various types of cells. The challenges now are to tailor protein therapy so that it can be used in people safely and with confidence that it will produce a beneficial result with minimal (or no) side effects.

An immediate challenge is to deliver the therapeutic protein so that it reaches its intended cell target and is not destroyed along the way. It may be possible to supply the protein in a pill that will resist degradation in the stomach. Another route that has been successfully used for the targeted delivery of some injected drugs is to package the protein inside molecules made in the laboratory called liposomes (LIP-a-sohmes). Liposomes are hollow spheres made of lipids (fats) that can be filled the therapeutic protein.

Finally, prolonging the activity of a therapeutic protein in the body is desirable, since it would then have to be given to the patient less often. Designing proteins to resist degradation is another research goal.

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[*See Also* **Vol. 1, Chemotherapy Drugs; Vol. 1, Enzyme Replacement Therapy.**]

Skin Substitutes

Description

Sometimes when people are badly burned, or have a disease such as diabetes that prevents their wounds from healing, their natural skin does not grow back. Doctors need to cover the area, both to make it look more natural and to protect against infection. To cover an area of lost skin, doctors have used skin grafts (healthy skin that is used to replace damaged skin) from dead bodies or from the patient's own body. If the burns are too deep for this to be done, doctors can use artificial skin substitutes.

Skin grafts can often be rejected by the body's natural defenses, and artificial skin is only temporary. So scientists have been developing new, tissue-engineered (also called bioengineered—artificial products that are made from natural biological materials) skin substitutes that heal more like real skin.

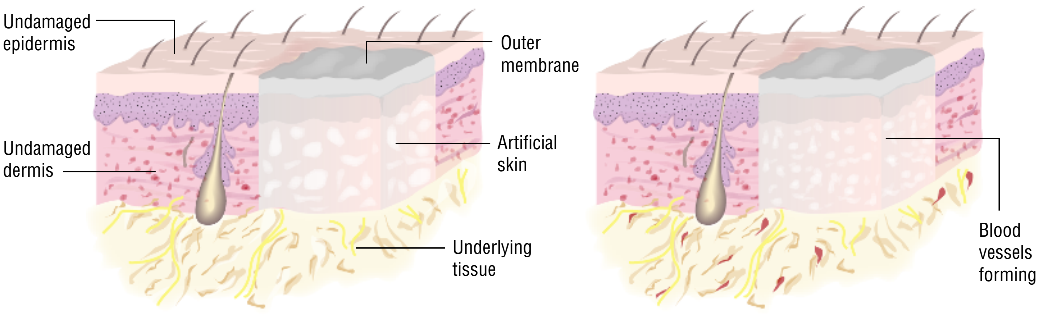
Scientific Foundations

Skin is the largest organ in the body. It is made up of two layers: the dermis and the epidermis. The dermis is the bottom layer. It contains blood vessels, nerve cells, and sweat glands. On top of the dermis is the epidermis, the part of the skin that can be seen. The epidermis contains cells that produce keratin, a substance that makes skin strong. The epidermis also constantly makes new skin cells. The old cells rise to the surface, where they turn into dead skin and flake off.

Although skin is able to regrow when it is damaged, it cannot regrow when both the dermis and epidermis have been destroyed. This sometimes happens when someone is badly burned, or has a disease that prevents their wounds from healing.

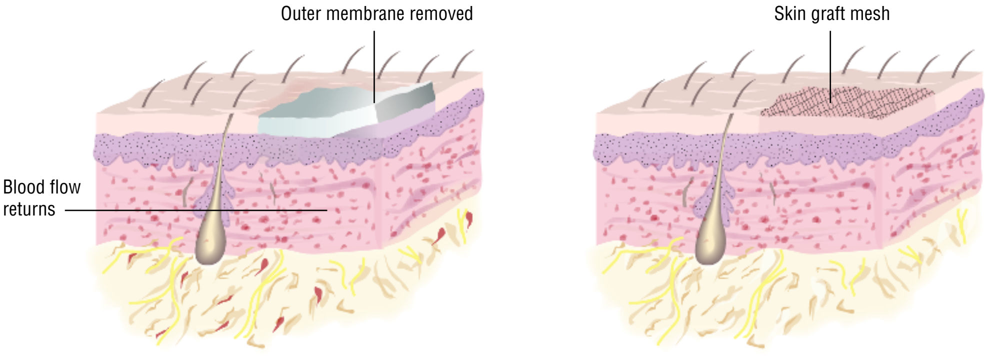
Skin substitutes

How artificial skin helps burns heal

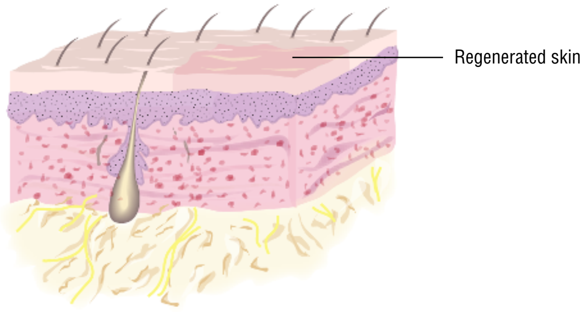

Undamaged epidermis
Outer membrane
Undamaged dermis
Artificial skin
Underlying tissue
Blood vessels forming

Severely burned area with artificial skin in place

One week after application


Outer membrane removed
Skin graft mesh
Blood flow returns

Two weeks or more after application


Regenerated skin

One to two months after application

Synthetic skin works by protecting the underlying tissues while providing a structure that allows regrowth of the skin. *Illustration by GGS Inc.*

Building a New Body

In the 1980s, scientists Robert Langer and Joseph Vacanti discovered that they could grow human skin in a lab. Their discovery not only enabled scientists to create skin substitutes, but it also paved the way for the creation of entire organs. The scaffold they discovered could be shaped like an organ, for example a liver. Then organ cells from the patient or a donor could be put on the scaffold. The cells would grow and divide, forming a new organ. The idea was to implant the organ in the patient's body and have the scaffold dissolve away. The challenge is to get blood vessels to regrow so that the organ can integrate naturally into the patient's body.

Doctors often use skin substitutes to cover open wounds. Skin substitutes protect against fluid loss and infection, and help the wound heal. There are four different types of skin substitutes that can be used to replace lost skin: autografts, allografts, synthetic skin, and tissue-engineered skin.

An autograft uses epidermal skin from another part of the patient's body. An allograft uses skin from a cadaver (a dead body) or from a pig. An allograft is only temporary because the person's body will eventually recognize the skin as foreign and reject it. Synthetic skin is usually made of silicone (an artificial material made of the element silicon and oxygen), collagen (a type of protein that makes up connective tissue), and a support layer of fiber. It is also temporary, because it cannot grow into the person's skin. Tissue engineered skin is a newer technology. It is made from real human cells and is designed to permanently replace lost skin.

Development

In the past, burn victims were left vulnerable to infection without skin to protect them. People with diabetes and other conditions that prevented wounds from healing would sometimes need to have their affected limbs amputated (cut off) in order to save their lives. Up until the late twentieth century, skin could only be surgically replaced using grafts from the patient's own body or from a donor. But patients sometimes did not have enough extra skin for a graft, and donor skin can be rejected.

As early as the 1970s, scientists learned how to grow human tissue in a lab. In 1986, Robert Langer (1948–) of the Massachusetts Institute of Technology and Joseph Vacanti of Massachusetts General Hospital pioneered a new method for growing human tissues. They

Words to Know

Allograft: Transplanted tissues or organs from donors of the same species.

Amputate: To cut off a limb or part of the body.

Autograft: A type of skin graft that uses tissue from another part of the patient's own body, and therefore has cells with the same genes.

Biodegradable: Able to be broken down by natural processes.

Cadaver: A dead body.

Circumcision: Removal of the foreskin of the penis.

Collagen: A type of protein that makes up connective tissue.

Dermis: The inner layer of skin. It is made up of connective tissue that gives skin its strength.

Diabetes: A disease in which the body cannot make or properly use the hormone, insulin.

Epidermis: The outer layer of the skin consisting of dead cells. It is the primary protective barrier against sunlight, chemicals, and other possible harmful agents. The epidermal cells are constantly being shed and replenished.

Fibroblast cells: Cells in the dermis layer of the skin that give rise to connective tissue.

Graft: A transplanted tissue.

Keratinocytes: Skin cells that make a protein called keratin, which protects the skin.

Silicone: A controversial substance that has been used in breast and other types of implants. It is classified as a high-risk category material by the FDA.

Tissue engineered (also called bioengineered): Artificial products that are made from natural biological materials.

figured out how to grow skin using a type of biodegradable (able to break down naturally) scaffolding as a framework. The first type of artificial skin made with real human cells was approved by the U.S. Food & Drug Administration in 1997.

Tissue-engineered skin is made using healthy skin cells from a donor (sometimes tissue that is removed from the foreskin of male babies during circumcision). The cells are seeded onto a scaffold. This is like a framework that molds the cells into a particular shape. The scaffolds are biodegradable, which means that they are absorbed into the skin without having to be removed surgically.

Scientists use natural skin-making cells to seed the scaffold. Then they make the cells multiply until they fill in the scaffold and create what looks like real skin. When the patient is ready, the skin is stretched over the wound. No stitches are needed—the tissue-engineered skin becomes integrated with the patient's natural skin. Some types of tissue-engineered skin are made from an artificial epidermis with a dermis made of real cells. Other types contain both dermal and epidermal cells. The cells in tissue engineered skin function much natural human skin.

Current Issues

Tissue-engineered skin can be made to look and feel like real skin, but it does not act entirely like skin. For example, it cannot grow blood vessels, so it has no real blood supply to feed it. This can cause the body to reject the skin, or cause the skin to lose function. Tissue-engineered skin also cannot grow hair, sweat, or heal (scab over) like natural skin because it lacks the cells to do these things.

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[*See Also* **Vol. 1, Anti-Rejection Drugs; Vol. 1, Bone Substitutes; Vol. 1, Collagen Replacement; Vol. 1, Organ Transplants; Vol. 1, Tissue Engineering; Vol. 1, Xenotransplantation.**]

Somatic Cell Therapy

Description

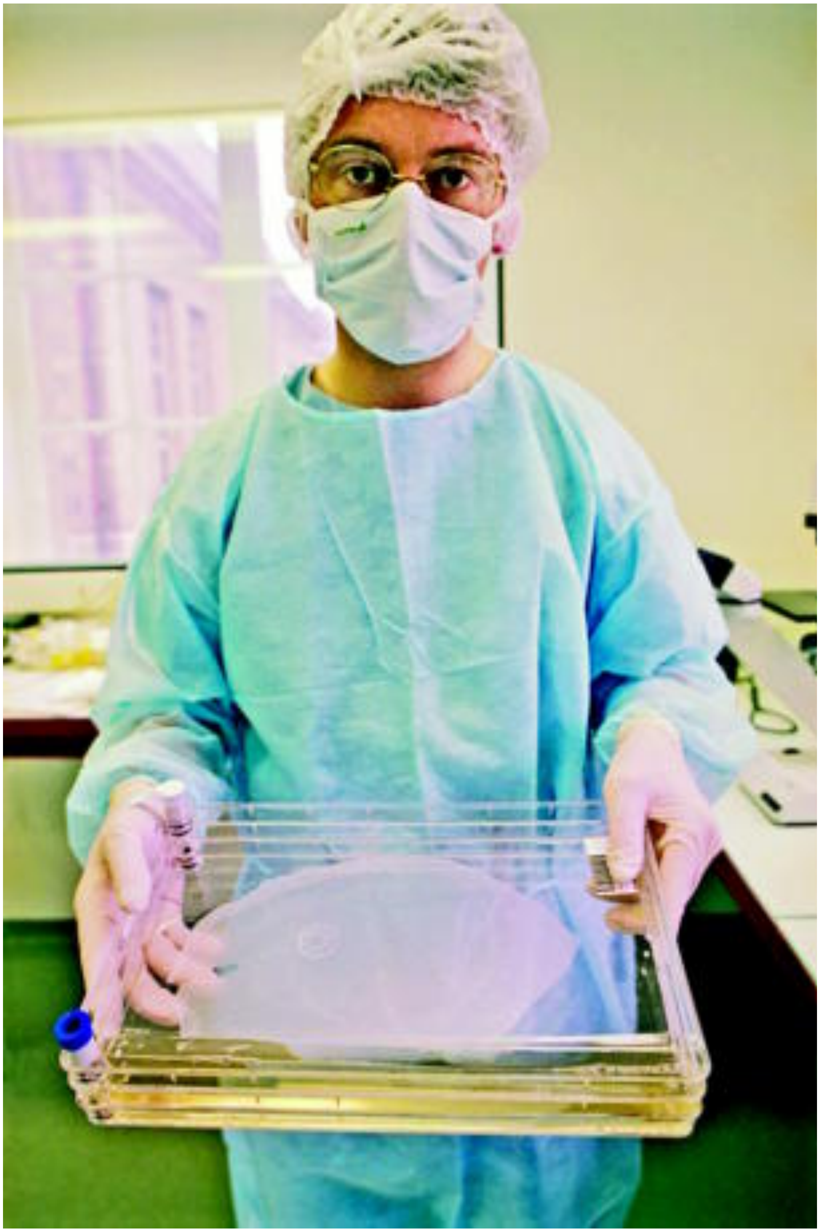
Somatic cell therapy, or cell therapy, is a set of techniques and scientific processes that are used to repair diseased cells of a human body by replacing them with healthier and scientifically processed new cells. This modern therapy can be used to treat a variety of diseases and conditions, such as cancer, spinal cord injuries, Parkinson's disease, and diabetes. A somatic cell is any cell in the human body except for egg cells and sperm cells.

In the case of diseases that cause the body's organs not to work properly, drug treatments may not work well over long periods of time. After that time, the only option that often remains is organ transplant, which is difficult and expensive to do and often fails. Scientists are hoping to develop somatic cell therapy so that plenty of healthy cells can be created to replace the disease-causing cells, resulting in a new treatment option.

Scientific Foundations

Cells are called the building blocks of life. They are the structural and functional units of a living organism. All organisms are either unicellular (composed of one cell) or multicellular (composed of many cells). In multicellular organisms, like animals and humans, different cells perform all the functions that are responsible for the overall performance of the organ or tissue that they compose.

Different type of cells make up the human body (such as blood cells, skin cells, or muscle cells), but all of them arise from a single cell—the fertilized egg, or zygote. These cells then replicate, or make copies of themselves. The cells that are produced during the early stages of human development are not specialized for any



A laboratory worker with a cell culture to be used as cell therapy in heart transplants. *© Dung Vo Trung/CORBIS SYGMA.*

specific organ and can contribute to all organs. These cells are known as embryonic stem cells. These cells progressively develop into specialized cells such as liver cells or kidney cells. Another type of stem cell, the adult stem cell, is found in specialized tissues, such as bone marrow (the soft material inside bones). They can generate all of the cells found in the blood.

Development

In 1968, a successful bone marrow transplant gave momentum to adult stem cell research. The concept of stem cells received more attention in the early 1980s, when improved technology for microscopic research and cultivation of stem cells in laboratories was developed. As mentioned earlier, there are two main types of stem cells, embryonic stem cells and adult stem cells.

In 1998, embryonic stem cells were developed by isolating cells from the inner cell mass of early embryos. Embryonic stem cells have become popular with medical researchers because they are easily available and can potentially be used to make any body cell. Adult stem cells, on the other hand, are obtained from adult tissues. Both embryonic and adult stem cells are capable of self-renewal as well as progressive development into specialized cells. Scientists can manipulate stem cells so that they can be used to replace damaged cells in the diseased organs in the body. This is called stem cell therapy.

A specific type of stem cell therapy is known as somatic cell nuclear transfer. This is a genetic procedure for cloning that involves removing the nucleus (the structure in each cell that contains genetic information) from a patient's somatic cell, usually a skin cell. This nucleus is then inserted into an egg cell from which the nucleus has already been removed. The egg cell now contains the patient's genetic material. It is allowed to divide in the laboratory until it forms a hollow sphere of cells called a blastocyst. The cells from the inner wall of the blastocyst are removed and used to develop a new stem cell line that has the patient's genetic material. Somatic cell therapy can be done in the body as well as outside the body.

According to scientists, the results of stem cell research and experiments have been very promising so far. Bone marrow transplants are an example of cell therapy in which the stem cells in a donor's marrow are used to replace the bone marrow cells of a patient who has leukemia or other cancers. Cell therapy has also been used to graft new skin cells to treat burn victims. In addition, it has been used in experiments to grow a new cornea for a sight impaired person. Experts suggest that with stem cell therapy, we may soon have effective cures for cancer, Parkinson's disease, diabetes, kidney disease, and paralysis caused by spinal injuries.

In a recent development, pancreatic cells grown from stem cells were implanted into the body of a diabetic patient and they began to produce insulin. Pancreatic cells are found in the pancreas, the

The First Somatic Cell Therapy

The first approved somatic cell therapy was performed on a four-year-old girl, Ashanti DeSilva, in September 1990. DeSilva had a very weak immune system caused by a deficiency of an enzyme known as adenosine deaminase (ADA). The therapy conducted on DeSilva helped her body produce the amount of ADA it needed for her immune system to work properly, and it saved her life. Today DeSilva is quite healthy and leads a normal life. However, she continues to receive gene therapy regularly, since the cells she receives only work for a few months.

gland in the human body that produces digestive enzymes and insulin. Nonetheless, there are several scientific challenges that have to be overcome before the true power of stem cell therapy can be fully harnessed.

Current Issues

Somatic cell therapy is a relatively new science, but dramatic results in this area have caused great optimism in the scientific community. However, there are several technical challenges and ethical issues that have caused intense debate in society. It is still difficult for scientists to work with stem cells. After the cells are identified, scientists need to develop the right biochemical solution that will enable the stem cell to develop and differentiate into the cell type they want. In addition, the cells that are implanted into the human body must learn to function in harmony and coordination with the body's natural cells. The possibility of tissue rejection by the body's immune system is another challenge. Finally, uncontrolled growth of the new transplanted cells could lead to diseases, such as cancer.

In the last few years, owing to their potential role in cloning humans, ethical concerns have arisen over embryonic stem cell research and somatic cell nuclear transfer. Extraction of embryonic stem cells may destroy the embryo and, in the words of the several critics, destroy a human life. However, advocates of stem cell research argue that the embryonic cells do not yet have any human characteristics.

In 1973, the U.S. government prohibited the use of federal funds for human embryo research. Ever since, there has been a continuing debate about whether the government should cancel or continue

Words to Know

Adult stem cell:	A renewable and unspecialized cell found among specialized cells in a tissue or organ.
Cells:	The smallest living units of the body which together form tissues.
Clone:	A cell or organism that contains the identical genetic information of the parent cell or organism.
Embryonic stem cell:	A stem cell found in embryos about a week old. Descendants of one of these cells can be any kind of tissue. These cells can reproduce indefinitely in the laboratory.
Enzyme:	A protein that helps control the rate or speed of chemical reactions in the cell.
Nucleus:	A compartment in the cell which is enclosed by a membrane and which contains its genetic information.
Somatic cell:	Cells that are part of the body but are not in the germline (able to pass their DNA on to future generations). Any type of cell in the body that is not a sperm or egg cell.

the ban. In 2000, President Bill Clinton allowed funding of research on cells derived from aborted human fetuses, but not from embryonic cells. In 2001, President George W. Bush restricted federal funding to research using existing human embryonic stem cell lines created before to his announcement.

The future of cell therapy continues to be debated by doctors, scientists, and society as a whole. However, scientists around the world agree that before somatic cell therapy becomes a reality, significant research is still required.

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[*See Also* **Vol. 1, Stem Cell Lines; Vol. 1, Stem Cells, Adult; Vol. 1, Stem Cells, Embryonic.**]

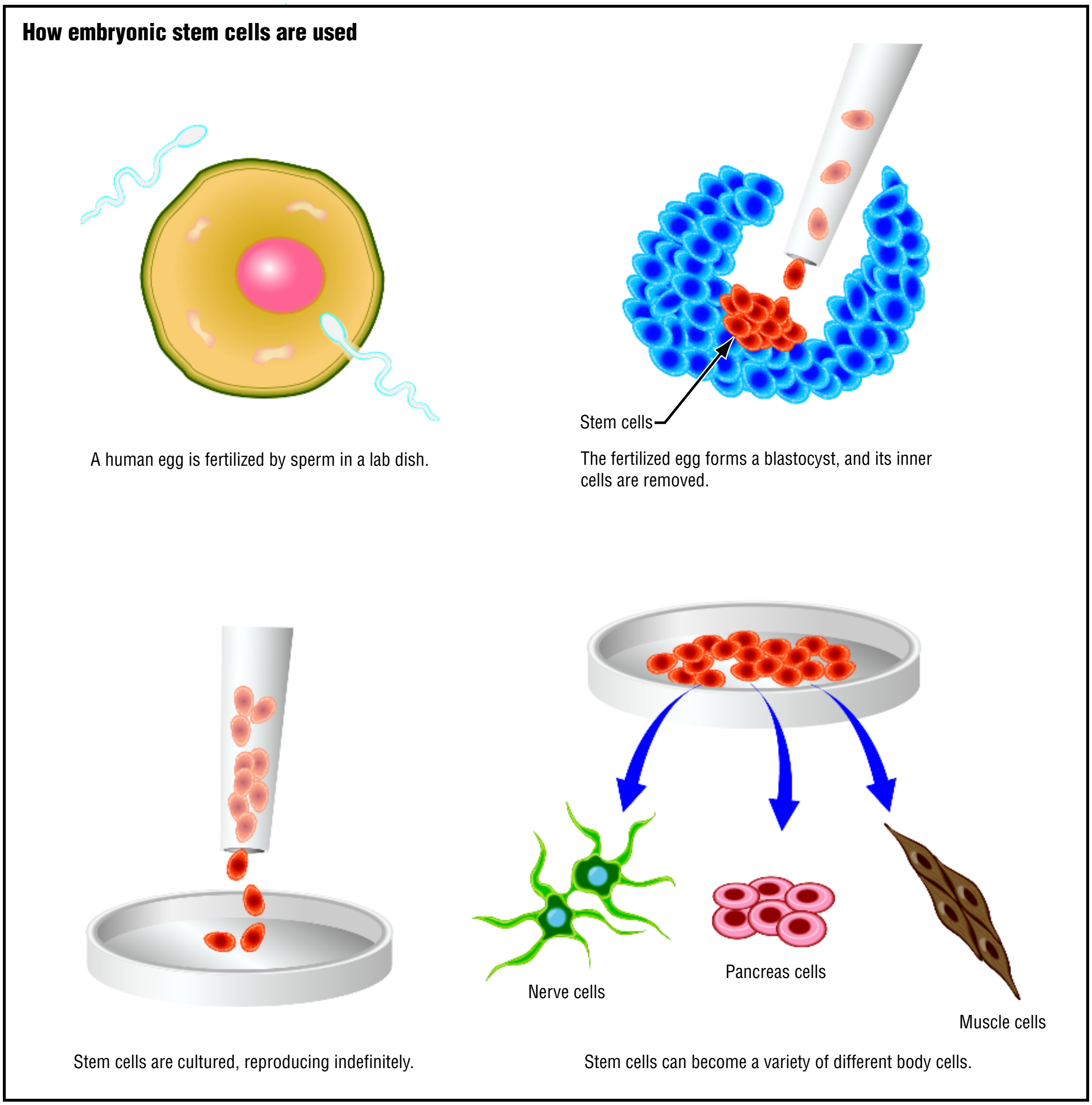
Stem Cell Lines

Description

There are about 200 types of cells in the human body: blood cells, brain cells, muscle cells, liver cells, skin cells, and more. All these types of cells (except egg, sperm, and red blood cells) contain a complete set of human DNA molecules. DNA is short for deoxyribonucleic acid, the molecule used by all living things to pass on traits to offspring. Because they contain a complete set of DNA, all cells could in theory make any other kind of cell. In practice, however, this does not happen. A DNA molecule in a cell is always telling the cell how to build molecules, like a book of recipes being used to cook many dishes. There are also molecules that attach to DNA and make different parts of it active or inactive—turn some of its recipes on or off. Different cell types grow differently because different parts of their DNA are turned on or off.

Single cells make new cells by growing to a certain size, copying their DNA, and then splitting in two. Each half gets a copy of the DNA and becomes a new cell. However, once a cell's DNA has been set for a certain kind of function, such as being a nerve cell, that cell can no longer divide.

There is only one kind of cell that can keep on dividing in the body, and that is a stem cell. There are several kinds of stem cells. All of them can give rise to other kinds of cells. Some stem cells—those found in embryos a few days old—can give rise to all 200 kinds of body cells. This is exactly what happens when a fertilized egg cell grows into a baby: the fertilized egg divides into two cells, then four, then eight, and so on as the embryo grows. A series of cells descended from each other is called a cell line. In an embryo, one cell line becomes heart muscle cells, another brain cells, another skin cells, and so on, until a baby is formed who has all 200 or so types of cells.



A human egg is fertilized by sperm in a lab dish.

The fertilized egg forms a blastocyst, and its inner cells are removed.

Stem cells are cultured, reproducing indefinitely.

Stem cells can become a variety of different body cells.

How embryonic stem cells are used to produce different types of body cells. The cells that are cultured from a single blastocyst become a stem cell line. *Illustration by GGS Inc.*

Once the body is formed, it still contains stem cells. But these stem cells are not as flexible as the ones in the young embryo. They can divide to produce some kinds of cells, but not others. For this reason, the stem cells in the young embryo are called "pluripotent" (pronounced ploor-IP-oh-tent). *Pluri* means "many" and *potent* means "having power." A pluripotent stem cell has the power to produce many kinds of cells.

The stem cells in the body are called adult stem cells (even though babies and children have them too). Adult stem cells make only one type of cell or sometimes several types, but never as many types as embryonic stem cells make. Adult stem cells make it possible for skin, muscle, and other tissues to heal after being damaged. Each kind of tissue has its own kind of stem cell.

Stem cells are special because they have the power to give rise to other kinds of cells. There are some medical treatments that use this power, and many more are being investigated.

Scientific Foundations

When taken out of the body, ordinary cells can be made to make new cells in a dish of nutrients. (The nutrient or food used is a thick liquid called a culture medium that is specially made for cells to live in.) But they can only reproduce or divide about fifty times. After that, they die out. This limit on the number of generations is called the Hayflick limit, after American professor of anatomy Leonard Hayflick (1928–), the person who discovered it in 1965. But embryonic stem cells have no Hayflick limit. No one knows how long an embryonic stem cell line can continue. Once a line of stem cells has been found, it can be kept going for years and be studied in laboratories around the world. Some human embryonic stem cell lines have been living since 1998. Adult stem cell lines do not last in this way because after a while they differentiate, that is, the new cells begin to look like cells from a particular tissue rather than like stem cells. Then they die out.

Development

Scientists have known for over a century that just a few cells in the embryo give rise to all the different kinds of cells in the body. However, it was not until about forty years ago that they began to understand the differences between stem cells and ordinary cells. Embryonic cells from mice were first isolated in the 1960s and used to start cell lines. Adult stem cells were first used to treat disease in the 1960s. The stem cells in bone marrow, which give rise to blood cells and some other types of cell, can be used to treat the kind of cancer known as leukemia.

It was not until 1998 that human embryonic stem cells were found. They were taken from embryos at a very early stage of growth—only three to five days after fertilization (the coming together of an egg and a sperm to make a single cell). At that time, the embryo is a ball of a few dozen cells. It has no brain, heart, limbs, or other organs.

Treating Parkinson's Disease

As of 2006, some scientists believed that they were close to finding a way to use stem cells to treat Parkinson's disease. In Parkinson's disease, the nerve cells that control the muscles break down. The limbs of people with Parkinson's disease shake or stiffen, and these people can no longer move normally. One out of every fifty people over sixty-five years old has Parkinson's disease. Researchers have found that they can treat Parkinson's disease in mice using embryonic stem cells. They add a gene to the stem cells to make them grow into nerve cells, then add the new cells to the brains of the sick mice. Once there, the new cells grow and the mice can move around better. Even if the same method will work for people, it will probably be years before an effective treatment is developed.

Current Issues

There are two kinds of issues or arguments about stem cells. First, there are factual questions about stem cells that scientists have not answered yet. Scientists do not know how to tell stem cells to make new cells of the right kind exactly where they are needed, so they cannot yet treat most diseases and injuries using stem cells. Also, they do not know where adult stem cells come from. A new kind of stem cell, the spore-like cell, was only discovered in 2001. The spore-like cell is very small and tough. Scientists still know very little about spore-like stem cells.

Second, there are ethical issues. Ethical issues are arguments about right and wrong. Some people think that it is wrong to use embryonic stem cells in research or to cure diseases because, they say, even when the embryo is only a few days old, shaped like a ball of ten or fifty cells that all look alike, it is already a human being with full human rights. Because of the objections from people who have these beliefs, the government of the United States has refused to fund the creation of new human embryonic stem cell lines since the late 1990s and has barred federal government funding for research using human embryonic stem cells since 2001. However, it is still legal for people to create and use human embryonic stem cell lines with private (non-government) money. Other people argue that the government should fund embryonic stem cell research because the benefits to sick people could be so great. They do not agree that the embryo is a human being at such an early stage of development.

Words to Know

Adult stem cell: A renewable and unspecialized cell found among specialized cells in a tissue or organ.

Cell line: Series of cells descended from each other like the generations of a family.

Culture medium: A substance that supports the growth of bacteria so they may be identified.

Deoxyribonucleic acid (DNA): The double-helix shaped molecule that serves as the carrier of genetic information for humans and most organisms.

Embryonic stem cell: A stem cell found in embryos about a week old. Descendants of one of these cells can be any kind of tissue. These cells can reproduce indefinitely in the laboratory.

Parkinson's disease: Disease of the nerves that causes the patient to gradually lose control of their muscles. Loss of a chemical in the brain called dopamine causes shaking and muscle stiffness.

Spore-like stem cell: An unspecified cell that remains in a dormant state in the body until they are stimulated to divide and form specialized cells.

Stem cell: An unspecialized cell that can divide to form other types of specialized cells in the body. Stem cells give rise to cells that have specialized form and function such as nerve or muscle cells.

There are no ethical arguments about research on adult stem cells, since adult stem cells can be taken from a living person without hurting them, or from a person who died from age, disease, or accident.

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[*See Also* **Vol. 1, Bioethics; Vol. 1, Bone Marrow Transplant; Vol. 1, Somatic Cell Therapy; Vol. 1, Stem Cells, Adult; Vol. 1, Stem Cells, Embryonic.**]

Stem Cells, Adult

Description

An adult human body contains about 100 trillion cells. Most cells do not last a lifetime. Some cells, like those that line the throat, last only about a week. Others, like muscle cells, can last for fifteen years or more. Whenever a cell dies, it must be replaced by a new one. New cells come from a special type of cell that is found in every kind of body tissue. These cells are called adult stem cells (because new cells "stem from" or arise from them). Adult stem cells do not do the specialized jobs of the cells around them; they do not contract like muscle cells, or send messages like nerve cells, or sense light like the cells at the back of the eye. Their main job is to make new specialized cells to replace those that die.

Stem cells must make new stem cells, too, to replace themselves as they die off. This is called long-term self-renewal. Because of self-renewal, there are always fresh stem cells in all the tissues of the body, ready to replace lost cells.

There are about 200 types of cells in the human body: blood cells, brain cells, muscle cells, liver cells, skin cells, and more. Most of these tissues have their own stem cells, which usually produce new specialized cells for just that one kind of tissue. Stem cells are rare. For example, in the bone marrow, where blood cells are made, only about one cell in 10,000 or 15,000 is a stem cell.

Besides the adult stem cell—which, despite its name, is also found in babies and children—there is at least one other kind of stem cell, the embryonic stem cell. Embryonic stem cells are found in embryos about three to five days after fertilization (the joining of the egg and sperm cell). At that time, the embryo consists of a ball of a dozen or so cells that all look alike. Embryonic stem cells are different from adult stem

Luc Douay, whose team at the St. Antoine Faculty of Medicine in Paris developed a technique to produce functional, mature, human red blood cells from adult stem cells. *VOISIN/Photo Researchers, Inc.*

cells because an embryonic stem cell can give rise to any kind of cell in the body. Adult stem cells do not have this ability.

Embryonic stem cells can also be kept alive for many generations outside the body, in a laboratory dish. They split, grow, and split again, producing new copies of themselves, year after year. Adult stem cells cannot do this. After a certain number of generations, adult stem cells start to look like the specialized cells of the tissue they were taken from, and then they lose their ability to keep on dividing. A laboratory culture of adult stem cells will die off after about a year. But a culture of embryonic stem cells can live for many years—nobody knows how long.

Scientific Foundations

There are two ways to tell whether a cell found in the body is a stem cell or not. The first is to label the cells and then track them in the body to see if they give rise to specialized cells (for example, muscle cells). Labeling is usually done by adding radioactive material to the cells; they can then be tracked by measuring their radioactivity. (Radioactivity is the ability that some elements have to give off energy and smaller particles when they disintegrate.) The other way to see if a kind of cell is a stem cell is to take the cells out of the body and raise them in dishes in the laboratory. If they can be made to give rise to specialized cells, they are stem cells.

Development

For over a hundred years, biologists have known that the body must have something like adult stem cells. They knew that skin cells and blood cells died quickly and must be replaced somehow. Every second, the body loses two million red blood cells and makes two million more. But red blood cells cannot make other red blood cells because they do not have any deoxyribonucleic acid (DNA, the molecule that all living things use to pass on traits to their offspring). Therefore, another kind of cell must make red blood cells.

In the 1950s, researchers began to hunt for the stem cells that make blood cells. In 1961, a Canadian team discovered stem cells in the bone marrow. These cells are called hematopoietic cells (pronounced hee-mat-o-poy-ET-ik), which is Greek for “blood-making.” Hematopoietic stem cells make all the blood cells in the body, including white blood cells, red blood cells, and platelets.

In the kind of cancer called leukemia, cells in the bone marrow start to reproduce out of control. Since 1968, some kinds of leukemia have been treated using hematopoietic stem cells. Doctors take healthy hematopoietic stem cells from the patient’s bone marrow and grow them outside the body. Then they kill all the other cells in the bone marrow, including the cancer, with radiation. The hematopoietic stem cells can then be put back into the bone marrow,

Not Just Junk

In 2001, a whole new type of cell, the spore-like stem cell, was discovered by Dr. M. P. Vacanti and his co-workers. The Vacanti group showed that extremely small cells—only a thirtieth or less the volume of a normal cell—exist in almost all tissues of the body. They called these cells ''spore-like'' because spores can survive extreme cold, extreme heat, and lack of oxygen, and so can these cells. Nobody had ever noticed the spore-like cells before because they are so small. One scientist, when Vacanti first pointed them out under a microscope, told him they were ''just junk.'' But the Vacanti group showed that the tiny spore-like cells are living stem cells by culturing them in laboratory dishes and watching them give rise to cells resembling the tissues they are taken from. Very little is known yet about what spore-like stem cells do.

where they grow and spread and replace all the kinds of bone-marrow cells and blood cells that the body needs. Experiments with mice have shown that a single hematopoietic cell can repopulate the entire blood-cell and immune system of the body, which contains trillions of cells.

Current Issues

In recent years, scientists have found that there are stem cells in all (or almost all) of the tissues in the body. But they still do not know where exactly the stem cells come from. They also do not know whether most adult stem cells can give rise to types of cells other than the tissues they are found in. This property is important because doctors may be able to use it to treat some diseases. For example, if adult stem cells could be forced to make new nerve cells, people paralyzed by severed spinal cords might be able to grow new nerves and use their bodies again. (The spinal cord is the large bundle of nerves that connects the brain to most of the body.)

It is still easier to treat diseases with embryonic stem cells than with adult stem cells. However, scientists would rather use adult stem cells. There are two reasons for this. First, some people think it is wrong to use embryonic stem cells because they come from embryos. These people believe that even when an embryo is only a few days old and has no brain, heart, or other organs, it is already a human person and must not be used for anybody else's benefit. Although most doctors and scientists do not share this belief, the government of the United States, which pays for most of the medical research in the country, will not pay for research that uses embryonic stem cells.

Words to Know

Adult stem cell: A renewable and unspecialized cell found among specialized cells in a tissue or organ.

Embryonic stem cell: A stem cell found in embryos about a week old. Descendants of one of these cells can be any kind of tissue. These cells can reproduce indefinitely in the laboratory.

Hematopoietic cell: A cells in the bone marrow that gives rise, by splitting, to all the various kinds of blood cells. *Hemato-* means blood and *-poietic* means making.

Spore-like stem cell: An unspecified cell that remains in a dormant state in the body until they are stimulated to divide and form specialized cells.

Stem cell: An unspecialized cell that can divide to form other types of specialized cells in the body. Stem cells give rise to cells that have specialized form and function such as nerve or muscle cells.

A second reason that scientists would rather use adult stem cells is that a patient's own stem cells could be used to treat their disease. This is already done with leukemia treatments. The body would welcome cells that come from its own cells, rather than trying to fight them off as invaders. However, it is still not practical to treat any human disease using adult stem cells, except for using hematopoietic cells to treat leukemia.

Knowledge about stem cells is growing quickly, and in the next few years diseases other than leukemia will begin to be treated using stem cells.

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[*See Also* **Vol. 1, Bioethics; Vol. 1, Bone Marrow Transplant; Vol. 1, Somatic Cell Therapy; Vol. 1, Stem Cells, Embryonic; Vol. 1, Stem Cell Lines.**]

Stem Cells, Embryonic

Description

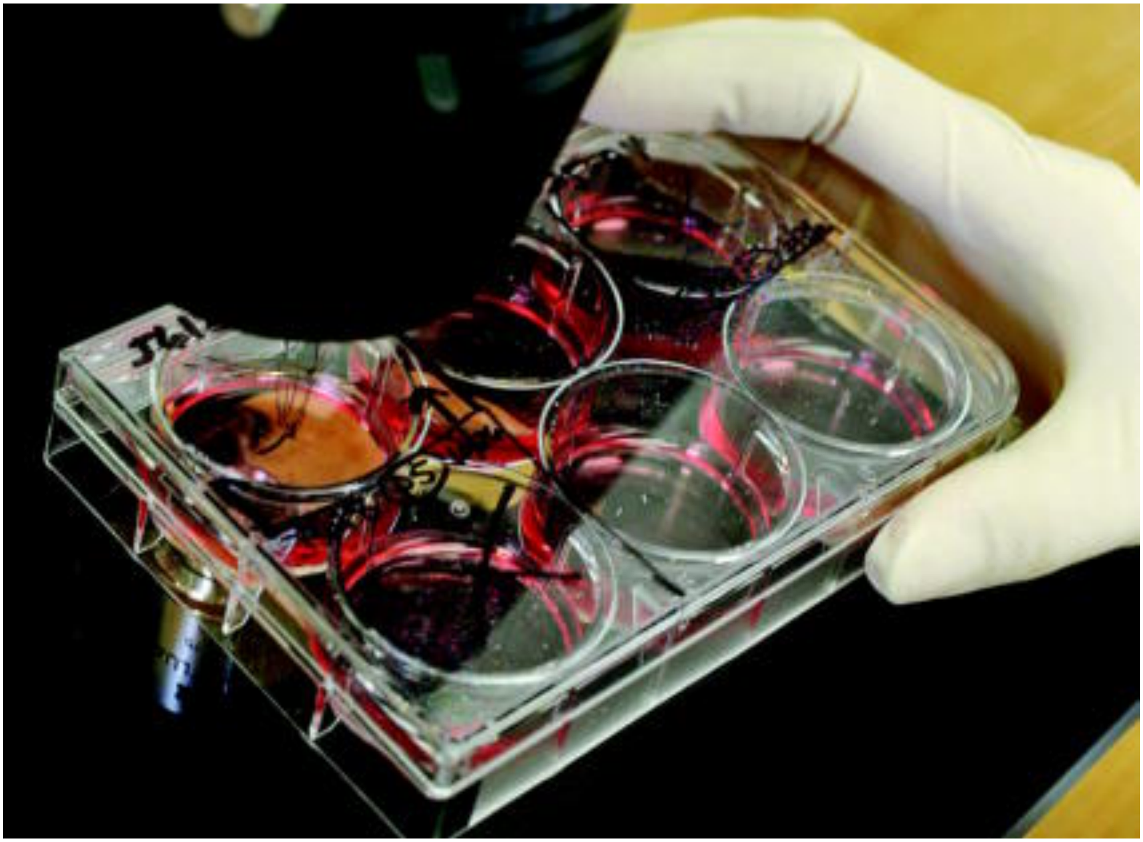
Embryonic stem cells are the cells in an embryo (a human being in its earliest stages of development) that will ultimately develop into every cell, organ, and tissue in the body. Because of their ability to become many different cell and tissue types, scientists believe that embryonic stem cells have the potential to treat many different diseases. They also have the potential to generate entire human organs, which could help the thousands of people who are waiting for organ transplants. However, research is just beginning into the nature of these cells, and any treatments that may come from embryonic stem cells are many years in the future.

Scientific Foundations

In human reproduction, a sperm from the man fertilizes an egg from the woman. The nuclei (plural of nucleus, the center part of a cell that controls all its functions) from the egg and the sperm merge, forming a zygote (a fertilized egg). The cells begin to divide. After about a week, they form a ball of about 100 cells, called a blastocyst. The inner part of the blastocyst contains the stem cells. These cells are pluripotent, which means that they can develop into any cell or tissue in the body.

Scientists would like to be able to grow embryonic stem cells in a lab, then coax those cells to become the type of cell that is missing or malfunctioning in a certain disease. Embryonic stem cells have several possible uses:

- To grow cells that produce dopamine for patients with Parkinson's disease (a nervous system disorder caused by a lack of the neurotransmitter dopamine, which causes shaking and muscle stiffness).



Embryonic stem cells in a plate of liquid nutrients being examined in a laboratory. © *Kat Wade/San Fransisco Chronicle/Corbis.*

- To grow pancreatic cells that produce the hormone insulin for people with diabetes (a disease in which the body cannot make or properly use insulin).
- To grow nerve cells to replace those damaged in people with spinal cord injuries.
- To grow new heart muscle tissue to replace tissue that is damaged during a heart attack.

Development

In 1981, two different research groups were able to isolate embryonic stem cells from mice. In 1997, researchers were finally able to pull stem cells from human embryos. American researcher Dr. James Thomson and his team of researchers at the University of Wisconsin were the first to discover a method for isolating and growing human embryonic stem cells.

Researchers who work with embryonic stem cells usually obtain frozen embryos at the blastocyst stage leftover from fertility clinic

The Ethics of Embryonic Stem Cell Research

In 2001, United States President George W. Bush prohibited the use of federal money for embryonic stem cell research, with the exception of the twenty lines that already existed. In other countries, stem cell research is not only accepted, it is encouraged. In the United Kingdom and Singapore, the governments have invested a great deal of money in stem cell research. One study by researchers at the University of Michigan and Stanford University found that scientists in other countries were beginning to outpace the United States in embryonic stem cell research.

procedures. These are embryos that would normally be destroyed. Scientists then remove stem cells from the inner part of the blastocyst. Removing these cells destroys the blastocyst. The cells are placed in a culture dish that contains nutrients. In the culture dish, the cells grow and multiply many times. After a few months, thirty original cells may have divided into millions of embryonic stem cells. Cells that do not differentiate (change into a more specialized cell type) after growing for several months are called a stem-cell line. These are the cells that have the greatest potential to treat disease. A stem-cell line can be frozen and used over and over again in the lab.

To get stem cells to differentiate into blood cells, muscle tissue, or any other type of tissue, scientists can change the chemical composition of the dish in which they are cultured. Or, they can add certain genes (pieces of DNA that specify the production of proteins, which determine how the body functions) to the cells.

Current Issues

There is much public debate about the ethics (what is right and wrong) of destroying embryos to harvest their stem cells. When stem cells are taken out of an embryo, that embryo no longer can be implanted into a woman's uterus and grow into a baby. Critics of embryonic stem cell research say that destroying embryos is murder, regardless of its scientific potential. In 2006, researchers grew stem cells from a single cell taken from an embryo without destroying it, and are working to perfect the technique.

There is also the issue of federal funding of embryonic stem cell research. U.S. President George W. Bush said in 2001 that federal money could not be used for embryonic stem cell research, with the exception of the stem cell lines that were already in existence at

Words to Know

Blastocyst: A cluster of cells resulting from successful fertilization of an ovum (egg) by a sperm. This is the developmental form that must implant itself in the uterus to achieve pregnancy.

Diabetes: A disease in which the body cannot make or properly use the hormone, insulin.

Differentiate: To become a specialized type of cell.

Embryo: A stage in development after fertilization.

Ethics: The study of what is right or wrong.

Genes: Pieces of DNA that carry instructions for traits and diseases.

Leukemia: A cancer of the blood-producing cells in bone marrow.

Parkinson's disease: Disease of the nerves that causes the patient to gradually lose control of their muscles. Loss of a chemical in the brain called dopamine causes shaking and muscle stiffness.

Zygote: The cell resulting from the fusion of male sperm and the female egg. Normally the zygote has double the chromosome number of either the sperm or egg, and gives rise to a new embryo.

the time. Although government has not forbidden embryonic stem cell research, many universities and research centers rely on federal money to operate.

Because of the public debate about embryonic stem cells, many researchers are investigating the use of adult stem cells as another option for treating disease. Adult stem cells are already being used to treat blood disorders such as leukemia. Although adult stem cells can replace damaged or malfunctioning cells, their ability to differentiate is much more limited than that of embryonic stem cells. Therefore, the stem cells present in human bone marrow could probably never be used to create nerve cells for people with spinal cord injuries, for instance.

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[*See Also* **Vol. 1, Bioethics; Vol. 1, Gene Therapy; Vol. 3, Government Regulations; Vol. 1, Stem Cell Lines; Vol. 1, Stem Cells, Adult; Vol. 1, Therapeutic Cloning.**]

Synthetic Biology

Description

Synthetic biology is the activity of designing and making new biological parts, products, and systems that do not occur in nature. It also involves redoing existing biological systems for new purposes. Based in biology, chemistry, and engineering, synthetic biology involves making artificial biological systems rather than natural ones. Thus, synthetic biologists, or synthetic biology engineers, are researching the possibility of developing living machines (what are called bioengineered microorganisms) from chemical ingredients. Bioengineered microorganisms are tiny living things that have been changed artificially so they can be used in a particular way. They could help solve many of the world's problems in agriculture, human health and medicine, manufacturing, renewable energy and energy production, and the environment.

For example, with respect to human health, according to the National Center for Infectious Diseases, between 700,000 and 2.7 million people die from malaria each year around the world. The drug artemisinin, which comes from a plant, treats malaria but is too expensive for use in poor countries where most of the cases occur. However, synthetic biologists artificially made a medicine that works like artemisinin but is much less costly.

With respect to renewable energy, synthetic biologists are working to develop artificial systems to turn waste into energy and to turn sunlight into hydrogen. For example, cellulose, a major part of plants, could be a source of renewal energy if synthetic biologists find a way to use bioengineered microorganisms to take out energy stored in cellulose.

The environment may benefit from synthetic biology if synthetic biologists can develop bioengineered microorganisms to break down and decontaminate pollutants that are threats to humans. For example, synthetically made cells could be made to swim to a hazardous waste spill and decontaminate it.

Scientific Foundations

Synthetic biologists are involved with biological molecules in the twenty-first century like electronic engineers were involved with electrons (particles smaller than an atom that have a negative electric charge) in the twentieth century, and like mechanical engineers were involved with machine components in the nineteenth century. Electronic engineers made standardized electronic devices such as capacitors, resistors, and transistors that were used to make products in the electronics industry. Now, synthetic biology engineers are developing standardized biological devices for products in the biotechnology industry. These biological devices are compared to LEGO® toys because they can be put together in different ways.

By making standardized biological parts with different characteristics, bioengineers can build inexpensive devices and materials to process information, produce energy, change chemicals, make materials, provide food, and deal with human health and the environment. A type of engineered enzyme is now being used in laundry detergents. Recently, an Israeli computer scientist built a computer from biological molecules that was able to perform simple mathematical calculations.

Development

During the last half of the twentieth century, the advancement of synthetic biology has been helped by the discovery of the structure of deoxyribonucleic acid (DNA, an organism's genetic material), the mapping of the human genome (an organism's complete genetic content), and other developments in genetics. In 1978, Swiss biologist Werner Arber (1929–), American molecular biologist Daniel Nathans (1928–1999), and American biologist Hamilton O. Smith (1931–) received the Nobel Prize in Physiology or Medicine for their work with restriction enzymes in genetics research. Restriction enzymes are proteins that break apart DNA. The term synthetic biology was used for the first time to describe Arber, Nathans, and Smith's work.

Based on their work, other researchers in the last two decades of the twentieth century were able to modify the DNA molecule, along with analyzing individual genes. For example, biotechnology companies now use restriction enzymes to make synthetic medicines such as human insulin for diabetes patients.

The World's First Synthetic Biology Department Established

On July 2003, the world's first synthetic biology department was established within the Physical Biosciences Division at Lawrence Berkeley National Laboratory, which is part of the U.S. Department of Energy and is managed by The University of California. A research facility, named the Berkeley West Biocenter, has been established that involves the areas of synthetic biology, cell and molecular biology, cancer research, and quantitative biology.

The Biocenter scientists involved with synthetic biology work inside the Berkeley Center for Synthetic Biology. They try to understand and design biological systems and their components. In turn, the scientists develop techniques to help solve many problems that so far cannot be solved using naturally occurring means.

The first international conference on synthetic biology was held at the Massachusetts Institute of Technology in June 2004. The second conference was held in May 2006 at the University of California at Berkeley. Most of the work on synthetic biology occurs in the United States. However, several research groups work in Japan, Europe, and Israel. Leading U.S. companies involved with synthetic biology include Amyris Biotechnologies (Emeryville, California), Codon Devices (Cambridge, Massachusetts), and Synthetic Genomics (Rockville, Maryland).

Current Issues

Synthetic biology is a promising field that should create new products in such fields as agriculture, industry, medicine, and energy. As with many new technologies, risks sometimes occur in society. For instance, unintentional dangers can occur to human health. Other times, intentional weapons are made to hurt people. Some people worry about the safety and security of products made with synthetic biology. They fear that unnatural organisms could cause environmental problems or that synthetic biology products could be misused by terrorist groups.

Special safeguards are being put into place to make sure that dangerous bioengineered products are used for the right purpose. Hypothetically, terrorists could use standardized biological materials to recreate the smallpox virus or other deadly diseases. Even though medicines can be made through synthetic biology to cure

Words to Know

Bioengineered: The process of using engineering to solve medical problems.

Chromosome: A thread-shaped structure that carries genetic information in cells.

Deoxyribonucleic acid (DNA): DNA—The double-helix shaped molecule that serves as the carrier of genetic information for humans and most organisms.

Enzyme: A protein that helps control the rate or speed of chemical reactions in the cell.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Microorganism: An organism too small to be seen without a microscope, such as a virus or bacterium.

malaria, they can also be made into biological weapons that could kill large numbers of people.

Because the field of synthetic biology is in its early stage of development, issues concerning social, ethical, and legal problems are mostly being discussed by scientists and researchers. Environmental and ethics groups are beginning to raise their concerns with synthetic biological products as well.

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[*See Also* **Vol. 3, Biological Weapons; Vol. 3, Biorubber; Vol. 1, DNA Sequencing; Vol. 2, Genetic Engineering; Vol. 2, Genetically Modified Organisms.**]

Therapeutic Cloning

Description

Therapeutic cloning is the creation of an embryo (a human being in the earliest stages of development) by scientists in a lab in order to pull stem cells from it. Embryonic stem cells can grow into every type of cell and tissue in the body, such as heart cells, blood cells, or muscle cells. They may be used to treat diseases such as Parkinson's (a disease of the central nervous system that causes a person to shake and their muscles to become rigid) and Alzheimer's (a condition that affects the brain and interferes with thinking and memory), or to repair a spinal cord damaged by injury, among other uses. Eventually, embryonic stem cells may be able to grow into entire organs.

Therapeutic cloning is not the same as human cloning. With therapeutic cloning, an embryo is created only for the purpose of using its stem cells. With human cloning, an entire human being is created. Therapeutic cloning destroys the embryo before it can be implanted in a woman's uterus and have the chance to grow.

Scientific Foundations

During human reproduction, a sperm from the man fertilizes an egg from the woman. The fertilized egg begins to divide to form an embryo. Half of the genetic material in the embryo is from the mother; the other half is from the father. The cells in the inner part of the embryo are called pluripotent—they have the ability to become any type of cell or tissue in the body.

Scientists can also make an embryo in a lab using an egg that has had its nucleus (the part of the egg that contains deoxyribonucleic acid [DNA]) removed and an adult cell from anywhere in the

The Race to Clone

In November 2001, scientists at the company Advanced Cell Technology (ACT) in Massachusetts announced that they had created the first cloned human embryo. Although they technically created an early embryo, they were only able to get one of the eight eggs involved in their research to divide to six cells. In 2004, a team of scientists in South Korea led by professor Hwang Woo-Suk announced that they had cloned more than thirty human embryos, but the team was later accused of faking part of their research.

In 2005, researchers in Britain were able to clone an embryo from a human cell. Despite ethical concerns by some groups, research centers around the world continue to press forward with therapeutic cloning studies.

body. They insert the DNA from the adult cell into the egg, then stimulate the egg and cell to divide and form an embryo. The genetic material in a cloned embryo primarily comes from the adult cell used to create it.

Development

In 1953, American scientist James Watson (1928–) and British scientist Francis Crick (1916–2004) announced that they had discovered the structure of DNA in cells. Their discovery paved the way for all future research in human genetics. A series of advances in the technology of genetics eventually let scientists to clone the first human embryos for therapeutic research in 2001.

Therapeutic cloning is done by removing the nucleus, the "brain" of the cell which contains the genetic information (DNA), from an unfertilized egg. The nucleus is added to the DNA from a somatic cell taken from an adult (usually the patient who needs the treatment). A somatic cell is any cell in the body (for example, a blood cell or a liver cell) with the exception of a reproductive cell (sperm and egg). The egg is stimulated with a small electric shock or special chemicals to make it start to divide.

After a few days, the egg forms a ball of about one hundred cells. This ball of cells is a very young embryo called a blastocyst. The inner part of the blastocyst contains the stem cells. Scientists remove the stem cells from the embryo and grow them in a dish. The idea is to coax the embryonic stem cells to become a specific type of cell (for example, heart cells). Those cells would then be implanted in the patient to repair damage caused by disease or injury.

Words to Know

Blastocyst: A cluster of cells resulting from successful fertilization of an ovum (egg) by a sperm. This is the developmental form that must implant itself in the uterus to achieve pregnancy.

Embryo: A stage in development after fertilization.

Ethics: The study of what is right or wrong.

Nucleus: A compartment in the cell which is enclosed by a membrane and which contains its genetic information.

Pluripotent: Pertaining to a cell that has the capacity to develop into any of the various tissues and organs of the body.

Current Issues

Although embryonic stem cells hold great promise for treating diseases, scientists are still learning how to coax them to become the types of cells they want. For example, in the case of spinal cord injury, scientists first need to get embryonic stem cells to become nerve cells. Then, they have to implant those cells in the spinal cord and get them to act like real nerve cells.

Another issue deals with the ethics (the study of what is right or wrong) of creating human embryos for the purposes of scientific research. Some people are against therapeutic cloning. They say that an embryo is a life, and that destroying it is killing a human being. In 2001, United States President George W. Bush limited federal funding of therapeutic cloning research to the embryonic stem cell lines that were already in existence at the time. The United States subsequently proposed a ban on all therapeutic cloning, but it failed to pass through Congress.

There is also concern among some groups that the practice of therapeutic cloning could lead to the cloning of people. However, embryos cloned for therapeutic purposes are destroyed when their stem cells are removed.

Another less controversial therapy uses adult stem cells to repair diseased cells and tissue. Although adult stem cells do not have the potential to become as many different types of cells as embryonic stem cells can become, researchers are trying to manipulate adult stem cells in a way that will increase their potential for medical treatments.

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[*See Also* **Vol. 1, Bioethics; Vol. 1, Somatic Cell Therapy; Vol. 1, Human Cloning; Vol. 1, Nuclear Transfer; Vol. 1, Stem Cells, Embryonic.**]

Tissue Banks

Description

Tissue banks are facilities that collect, process, identify, store, and distribute tissues used for tissue transplantations into human beings. Tissues are groups of cells within the human body, such as arteries, blood, bones, bone marrow, cartilage, corneas, heart valves and muscles, skin, sperm, tendons, and veins. There are four main groups of tissues: connective tissue (cells holding together parts of the body), epithelium tissue (layers of cells protecting internal organs and external surfaces), muscle tissue (cells containing pieces that stretch and bend), and nerve tissue (cells surrounding the brain, spinal cord, and nervous system).

Some tissue banks specialize in certain tissues. When this specialization occurs, they are called by such names as blood banks, sperm banks, and skin banks, to name a few.

The most common tissue collected at tissue banks is blood. This blood is used in blood transfusions, often for patients undergoing surgeries. Other tissues commonly transplanted include blood vessels, bones, bone marrow, cartilage, corneas (skin covering the eyeball), skin, and tendons (tissue that connects a muscle and a bone).

There are many different types of problems that require surgeries involving tissue replacement. Consequently, many tissue banks exist throughout the world. A variety of procedures may require the transplantation of tissues include orthopedic surgeries to repair torn tendons of the knee, ophthalmologic surgeries to treat diseased corneas in the eye, and cardiovascular surgeries to correct malfunctioning heart valves.

Scientific Foundations

The popularity of tissue transplantation created the need for tissue banks. Tissue transplantation is the process of taking tissue from the

Worker in a brain bank at Harvard Brain Tissue Research Center in Belmont, Massachusetts. This tissue bank holds 5,000 brains. © *Reuters/Corbis.*

body of a donor and placing it into the body of a recipient. Two types of transplantation are possible: allograft and autograft. Allograft tissue is donated by one person so that it can be stored and preserved for transplantation into another person.

Autograft tissue is tissue taken from a person who needs a tissue transplantation and, then, stored and preserved so that it can be later placed into another part of that same person's body. Skin is commonly transplanted in this way. An autograft transplant is usually a safer and faster way to transplant tissue. Allograft tissue takes longer to transplant into the body, but, only one site (the transplant site) needs to heal since the tissue comes from another human. Since tissue transplants of both types are not subject to rejection by the immune system like organ transplants, immunosuppression (anti-rejection) drugs are not needed during and after the surgery.

Development

In the first quarter of the twentieth century, medical researchers developed surgical techniques to perform tissue transplants of bones,

American Association of Tissue Banks

The American Association of Tissue Banks (AATB, http://www.aatb.org/) is a nonprofit scientific organization founded in 1976 to provide high quality tissues to hospitals and surgeons for transplant into patients. Beginning in 1986, the AATB began offering an Inspection and Accreditation Program for qualifying tissue banks. The AATB also offers individuals within the tissue bank field an examination called the Certification of Tissue Bank Personnel. The examination tests a person's knowledge of such important topics as donor and tissue suitability, retrieval of tissues, tissue processing, techniques of decontamination, quality control, labeling, recordkeeping, product testing, and various clinical applications and procedures.

corneas, and tendons. The U.S. Navy Tissue Bank, established in 1949, provided the first bone and tissue processing and storage facility in the United States. It was essentially the first U.S. tissue bank. French immunologist Jean-Baptiste-Gabriel-Joachim Dausset (1916–) introduced matching of blood types between tissue donors and recipients (what is now generally called tissue matching for all types of tissues) in 1958.

Between the late 1970s and the early 1980s, tissue banks were first organized to meet the need to gather, store, and distribute tissues to hospitals. By 1986, many nonprofit bone banks were in operation in the United States. In 1993, the U.S. Food and Drug Administration (FDA) began to regulate some aspects of U.S. tissue banks. Additional regulations were implemented in 1997, including the registration of all tissue processors. Further regulations came in during the first decade of the twenty-first century.

Current Issues

Tissue banks process tissues that are needed for hundreds of thousands of people in the United States each year. According to the FDA, about one million tissue transplants were performed in the United States in 2004, nearly three times as many as in 1990. However, many questions are raised concerning the use of human tissues in transplantations as more are used in biotechnology applications, medical treatments, and scientific research. Laws regarding the use of human tissues have not kept pace with scientific developments, and this has added to the debates. Some of the major issues regarding the use of human tissues include: the ethical versus the unethical uses of tissues; legal aspects of using tissues; safeguards for tissue donors and recipients; commercial uses of tissues; and safety of tissues for medical purposes.

Words to Know

Allograft: Transplanted tissues or organs from donors of the same species.

Autograft: A type of skin graft that uses tissue from another part of the patient's own body, and therefore has cells with the same genes.

Epithelium: The layer of cells that covers external and internal surfaces of the body. The many types of epithelium range from flat cells to long cells to cubed cells.

Hepatitis: General inflammation of the liver; may be caused by viral infection or by excessive alcohol consumption.

Human immunodeficiency virus (HIV): The virus that causes AIDS (acquired human immunodeficiency syndrome); HIV stands for human immunodeficiency virus.

Immunosuppression: The act of reducing the efficiency of the immune system.

Parkinson's disease: Disease of the nerves that causes the patient to gradually lose control of their muscles. Loss of a chemical in the brain called dopamine causes shaking and muscle stiffness.

Tissue: Groups of cells with a similar function.

Transplantation: Moving cells or tissues from their point of origin in one organism to a secondary site in the same or a different organism.

Many problems have occurred as tissues are processed from donors to recipients through tissue banks. Diseases and infections have occurred when tissues are not handled properly. In addition, the tissue bank industry was mostly unregulated from its beginnings in the 1970s to the late 1990s. Consequently, in 2004, the FDA issued additional and stricter safety standards for tissue banks to prevent disease and infection from being passed in tissue transplants. In addition, the FDA requires all tissue banks to be registered and regularly inspected. Currently, all tissue banks are screened for tissues that may contain dangerous diseases such as hepatitis B and hepatitis C (liver diseases) and human immunodeficiency virus (HIV, the virus that causes AIDS).

In recent years, issues regarding fetal tissue banks and the use of fetal tissues have been raised in the United States and around the world. Fetal tissue is tissue that is taken from a human fetus (an unborn child from three months of pregnancy to birth). Critics of the use of fetal tissues question the ethics of using tissues from aborted human fetuses for any type of research. Proponents state that suffering from diseases, such as Parkinson's disease, could be ended, or at least reduced, by further research involving fetal tissues.

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[*See Also* **Vol. 1, Anti-Rejection Drugs; Vol. 1, Bone Marrow Transplant; Vol. 1, Organ Transplants.**]

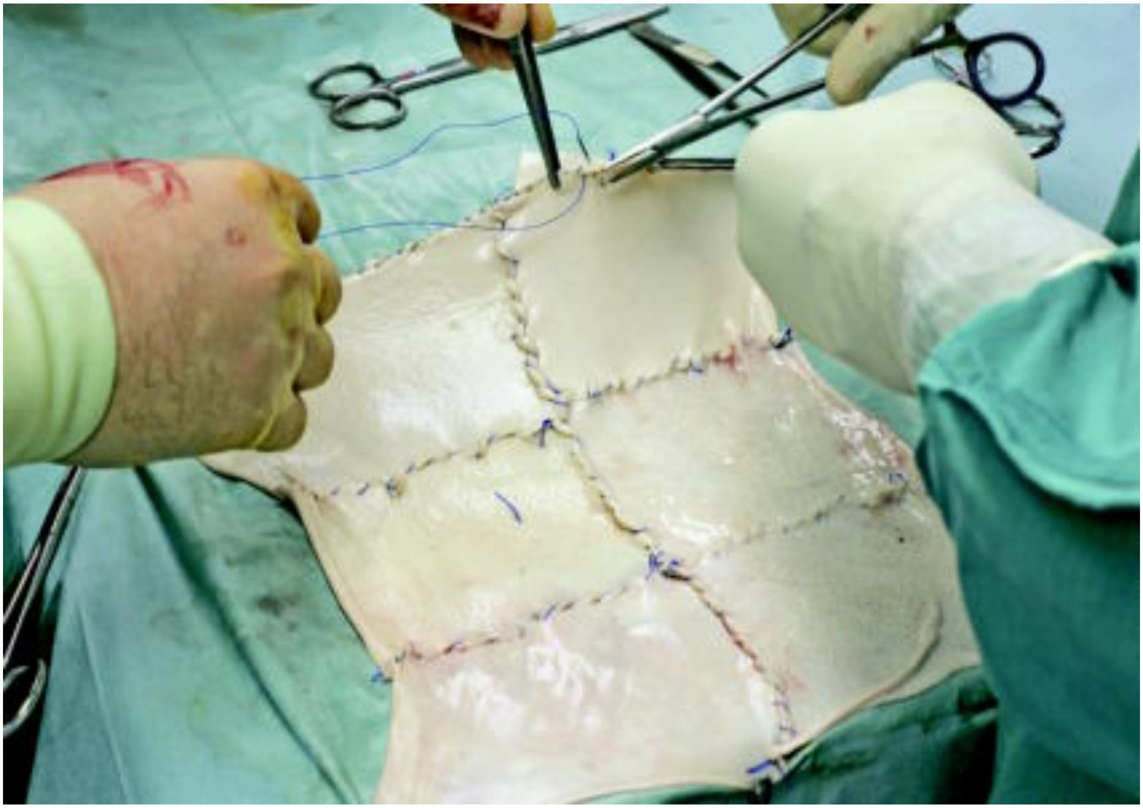
Tissue Engineering

Description

Tissue engineering is the collection of procedures used to make biological replacement tissues and organs such as blood vessels, blood, bones, cartilage, muscles, skin, stem cells, and bladders from synthetic or natural materials. It involves the fields of clinical medicine, bioengineering, and materials science and engineering. Tissue engineering uses natural cells and engineered materials to replace damaged or defective tissues and organs.

The need for transplant tissues and organs is growing in the United States and in industrial countries around the world. However, the supply of human and animal tissues has not met the demand for transplants. Lately, artificially grown tissues are helping to supply needed tissues for transplants. For example, the U.S. Food and Drug Administration (FDA) approved tissue engineered skin for burn victims and patients with serious skin sores or ulcers. It is likely that cartilage and bone will soon be grown to reduce arthritis pain; and that blood vessels, cardiac valves, and muscle tissues will be made to minimize cardiovascular disease.

In the future, custom-made bone marrow, corneas, hearts, kidneys, and livers will help minimize illnesses. The major U.S. research institutions pursuing tissue engineering include Columbia University, Massachusetts Institute of Technology, University of Pennsylvania, the University of Michigan, the University of Minnesota, Rice University, Stanford University, and the University of California at Berkeley. It was reported in 2001 that biotechnology companies that develop tissue-engineered products have a market worth of nearly $4 billion, and that they are spending, on average, 22.5 percent more every year.



Alloderm®, an artificial tissue made from human skin, being used in surgery to repair the stomach of a man severely injured in motorcycle crash. © *Sapone, Patti/Star Ledger/Corbis.*

Scientific Foundations

Cells are the main substance used for tissue engineering. Living cells used for research consist of several groups that are categorized by their source. Autologous cells are those taken from a donor who is also the recipient of the implanted tissues (in other words, using one's own tissue cells), while allogenic cells come from a donor who is different from the recipient, such as a brother and a sister. Xenogenic cells are provided from a donor who is of another species than the recipient. For example, tissue cells from a pig may be grown and implanted into a human. Isogenic cells come from identical organisms such as twins. Stem cells are identical cells with the ability to divide in a laboratory culture and grow into different types of specialized cells.

Generally, cells used for tissue engineering are grown on three-dimensional structures that are specially designed so the cells develop into functioning tissues. Once grown, the tissues are transplanted into the patient. Given enough time, the tissues are absorbed into the neighboring tissues and eventually look just like the original tissues.

First Human Receives Tissue-Engineered Organ

American physician Anthony Atala, director of the Institute for Regenerative Medicine at Wake Forest University School of Medicine, reported in March 2006 that for the first time a human received an organ artificially grown in the laboratory. Several bladders had been grown from the cells of young patients between the ages of four and nineteen years who had poor bladder function from birth. These bladders replaced the damaged bladders in these patients. Atala reported that he had been working since 1990 to build bladders from the patient's own cells. In the future, Atala will be working on developing twenty different types of tissues and organs grown artificially in the laboratory.

Development

American bioengineer Yuan-Cheng Fung, of the University of California at San Diego (UCSD), originated the term and idea of tissue engineering in 1985. At that time, Fung led the UCSD team in their National Science Foundation (NSF) research proposal titled, "Center for the Engineering of Living Tissues." Fung proposed the term again in 1987 at a NSF panel meeting, which led to a special NSF panel meeting on tissue engineering later that year. The first formal meeting involving tissue engineering met in 1988.

Between 1988 and 1993, the concept spread throughout the scientific community. In 1993, American physicians Robert Langer (1948–) and Joseph Vacanti published a tissue engineering paper in the journal *Science* that described their new process for growing human tissues. They defined tissue engineering as "an interdisciplinary field that applies the principles of engineering and life sciences toward the development of biological substitutes that restore, maintain, or improve tissue function." This definition formed the foundation for later work within tissue engineering.

Current Issues

Several problems have slowed the development of tissue engineering. First, the implanted cells are not always provided enough oxygen and nutrients to make them function properly. Secondly, once tissues have been successfully made, there is concern about how they are stored. Personal data is collected in order to identify the stored tissues. Thus, the privacy of donors can be at risk if such information is used for purposes other than medical.

Since human embryos are sometimes used in tissue engineering, critics say that tissue engineering is unethical. Those in favor of

Words to Know

Cartilage: A connective tissue found in the knees, tip of the nose, and outside of the ears; it provides flexibility and resilience to these structures.

Embryo: A stage in development after fertilization.

Nutrient: A substance that provides nourishment.

using human embryos state the numerous medical benefits produced from their use. Animal experiments are also performed in research involving tissue engineering. Similar ethical problems have been raised about using test animals.

There are many current and future uses for tissue engineering. Some of these uses include replacement or repair of defective or damaged bones, connective tissue, muscles, corneas, and blood vessels; replacement of skin due to serious burns; and restoration of cells involved in chemical activities within the body such as hormones. So far, cartilage, bone, and skin have been made in the laboratory. The making of blood vessels, blood, and organs such as the heart, lung, pancreas, and liver are expected to occur in the near future.

Before many of these uses can be accomplished, several technologies must first be completely developed. Two of these technologies involve the improved growth of cells without impurities and long-term storage of tissues that can be accessed around the world.

Tissue engineering can help reduce medical costs because fewer and less expensive treatments for major medical problems are needed. Since the use of transplant operations can be reduced, fewer complications, drugs, and recovery times are possible. In addition, improvements in the quality of life for patients should result. According to the Advanced Technology Program (ATP) of the National Institute of Standards and Technology, tissue-engineered medical solutions could drastically decrease the country's total healthcare costs.

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[*See Also* **Vol. 1, Bone Substitutes; Vol. 1, Organ Transplants; Vol. 1, Skin Substitutes.**]

Vaccines

Description

Vaccines are substances that trigger the body's defenses against a germ so that it can defend itself against the germ. Once a person has received the vaccine for a particular kind of germ, that person is immune to (will not become sick from) that kind of germ. For some diseases the immunity lasts for a few years, and for others it lasts a lifetime. Giving a vaccine (usually by injecting it directly into the blood or muscle with a needle) is called vaccination. Since vaccination makes a person immune to a disease, it is also called immunization.

Vaccines teach the body's active immune system how to defend the body against a specific germ. The active immune system is a network of cells throughout the body, mostly in the blood, that attacks cells and other bits of material that do not belong in the body.

Vaccines have been developed for over twenty diseases caused by viruses and bacteria, including smallpox, flu, hepatitis B, meningitis, rabies, rubella, polio, and whooping cough. For example, scientists say that as many as 500 million people were killed by smallpox during the twentieth century. But starting in 1967, a worldwide campaign to vaccinate smallpox succeeded in completely wiping out the disease in only about ten years. Today, the only smallpox virus known to remain on Earth is in storage in heavily-guarded laboratories in the United States and Russia.

Scientific Foundations

The blood contains cells called lymphocytes. These blood cells can go through stages, and there are always lymphocytes in the blood that are in all three stages: some are called naive cells, some are active cells, and some are memory cells. Naive (pronounced neye-EEV)

When influenza vaccines are not available, anti-viral drugs such as Tamiflu® usually shorten the course of the disease. *SPL/Photo Researchers, Inc.*

means inexperienced. Naive cells are inexperienced because they have not yet met a pathogen. When they do, they know it is a pathogen because it has certain chemicals on its surface that label or tag it as not belonging in the body. These chemicals are called antigens. When a naive lymphocyte finds an antigen, it becomes active. Active lymphocytes swallow up and remove pathogens.

When the infection is gone, most of these active lymphocytes die. However, some remain in the blood permanently. These are called memory cells. If they ever again meet the antigen that they first met when they were naive cells, they become active cells again, attacking the pathogen. They also divide quickly, making more active cells to attack that pathogen. This way, the body can attack an infection as soon as it appears.

Most vaccines work by putting antigens in the body, sometimes as part of dead or weakened pathogens. The antigens do not make us sick, but they do turn some naive lymphocytes into active cells and then memory cells. When living pathogens tagged with those antigens enter the body—smallpox or polio viruses, for example—the body attacks them at once with active lymphocytes.

This is a simplified account. The actual working of the immune system is more complicated.

Development

For centuries, people have noticed persons who had suffered the disease cowpox are immune to the disease smallpox. Although the

A Vaccine for Alzheimer's?

Alzheimer's disease is a condition where the nerve cells of the brains of elderly people slowly stop working, leading to memory loss, madness, and death. Some scientists think that Alzheimer's is caused by the buildup in the brain of chemicals called amyloid-beta peptides. They are trying to make a vaccine using a kind of vaccine called a DNA vaccine. In this kind of vaccination, DNA is put into body cells. This DNA acts like a recipe for an antibody, which is a substance that helps the body's immune system recognize germs. The antibody made by cells that have received the DNA vaccine are for amyloid-beta peptides. That is, these antibodies cause the body's lymphocytes to attack amyloid-beta peptides and destroy them. Researchers have had good success in mice with DNA vaccine, but are quick to point out that human beings are not simply large mice. What works in mice often does not work in people. It will be years before we can know whether an Alzheimer's vaccine for humans is possible. If it is, it will save millions of people from the suffering of Alzheimer's.

fact that infectious disease is caused by germs was not known, people experimented with vaccinating each other using fluids from people or cows infected with cowpox. (The viruses are close enough so that one can be used as a vaccine for the other, but cowpox is not deadly, unlike smallpox.) In 1796, an English doctor named Edward Jenner (1749–1823) tried the experiment for himself, using a farm boy as an experimental subject, and found that it worked. Vaccination for smallpox became commonplace. Vaccination for rabies was introduced in 1885, and for many other diseases in the years since. Today, research to find vaccines for HIV (human immunodeficiency virus, the virus that causes AIDS) and for other diseases is under way.

Current Issues

For centuries, some persons have opposed vaccination because they thought it would damage their health or their children's health or for religious reasons. Many people continue to oppose various kinds of vaccination. Scientists agree that some people have been killed or injured by vaccination, but most also agree that many more lives more have been saved through vaccination than have been harmed by it.

Words to Know

Alzheimer's disease: A degenerative disease of the central nervous system that generally afflicts elderly people and that can lead to memory loss and death.

Antibody: A molecule created by the immune system in response to the presence of an antigen (a foreign substance or particle). It marks foreign microorganisms in the body for destruction by other immune cells.

Immune system: A system in the human body that fights off foreign substances, cells, and tissues in an effort to protect a person from disease.

Lymphocyte: A cell that functions as part of the lymphatic and immune systems by attacking specific invading substances.

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[*See Also* **Vol. 1, DNA Vaccines; Vol. 1, HIV/AIDS Drugs.**]

Xenotransplantation

Description

Xenotransplantation refers to the transplanting of material including cells, tissues, or entire organs from a non-human species, such as a pig, chimpanzee, or baboon, to humans. The intent of xenotransplantation is to provide medical treatment to patients with urgent health problems, such as the deterioration of heart valves (which regulate the flow of blood through the heart) or kidney failure (in which the kidneys can no longer filter blood well enough to keep the person alive).

While transplantation of tissues or organs from another human is preferred, a suitable donor may not be available when a particular organ or tissue is urgently needed. Shortage of human organs is a problem for people in need of a transplant. More than half of those who require a life-saving organ transplant die before a suitable human organ can be found. Xenotransplantation can overcome this limitation. However, a number of practical and ethical considerations cloud the development of the technique.

Scientific Foundations

The use of non-human transplanted material began in the 1960s. In 1963–64, thirteen chimpanzee kidneys were transplanted into thirteen humans. Twelve people died within two months of their operation. However, one person lived nine months before dying, indicating that the use of animal organs had some potential for medical use. In 1964, a chimpanzee's heart was used to replace the failing heart of a person. Within two hours, the transplant was rejected by the body's immune system. Subsequent heart xenotransplants have also failed.

Baby Fae, the first infant to receive a baboon heart, in 1984. The newborn died less than a month after the transplant. © *Bettmann/ Corbis.*

The efficiency of the human immune system is the underlying reason for the poor track record of xenotransplantation, and immune rejection remains the biggest practical hurdle to successful xenotransplantation. The surface of tissues varies among different species and even between members of the same species. Normally, this is good, because it helps the body to fight diseases brought in by foreign matter, such as bacteria. However, the immune system can also recognize differences in transplanted material and mount an attack on it. Without the use of drugs that suppress the immune system, the transplanted cells will be destroyed and the transplant rejected.

Patients who have had a tissue transplant have a life-long dependence on immunosuppressive drugs to keep the body from rejected the transplant. The use of these drugs carries a risk, since a weakened immune system makes an individual more susceptible to infections that would otherwise be efficiently eliminated. This

A Xenotransplantation Ethical Dilemma

Over 60 million pigs are slaughtered each year to provide pork for the American diet. This creates a huge reservoir of potential donor tissues and organs. But, the considerable differences between pig and human tissue increase the possibility of immune rejection. To deal with this, scientists are genetically engineering pigs to make target tissues more closely related to their human counterparts. Pigs may someday contain organs that do not stimulate an immune response when transplanted into humans.

However, this artificially created similarity carries a risk. Disease-causing organisms that can infect the pig tissue may be more easily capable of causing human illness if present in the transplanted tissue. Is the risk of infection to an individual outweighed by the overall improved health that could result for society as a whole?

risk can be even more serious in the case of xenotransplantation, since an animal disease could, potentially, be transmitted to the human recipient. However, when the only other option is death, this risk can be worth taking.

Development

The concept of xenotransplantation is over a century old. Beginning in 1904, French surgeon Alexis Carrel (1873–1944) and his colleagues experimented with the transplanting of veins. Animal-to-human kidney transplants were first attempted by other scientists in 1906. The uniform failure of these early attempts led to the abandonment of xenotransplantation until the 1950s, when immunosuppressive drugs began to be developed.

Then as now, immune rejection is the paramount practical problem facing xenotransplantation. Because of this barrier, xenotransplantation of organs has mainly been used as an emergency measure as an attempt to buy some time while a more suitable tissue or organ can be located and transported to the patient.

Better success has been obtained when tissues or a component of an organ is transplanted. For example, xenotransplantation of animal heart valves has been performed hundreds of thousands of times since the procedure was first tried using pig heart valves in 1975 and cow valves in 1981.

The use of animal models has aided the development of xenotransplantation. For example, the transplantation of mouse or hamster hearts into rats is a good model of a type of immune rejection

Words to Know

Immune rejection: Immune system rejection of a foreign substance.

Xenograft: Tissues and organs used for transplantation that come from different animal species, like pigs or baboons.

Xenotransplantation: Transplantation of tissue or an organ from one species to another, for example from pig to human.

called acute vascular rejection. Furthermore, transplant studies using pigs as the donors and non-human primates as the recipients have demonstrated that suppression of the immune system is not sufficient to sustain the transplant. Production of protective proteins by the transplanted material is also required.

Current Issues

The spread of an animal infection to a human recipient via the donated tissue or organ (xenozoonosis) remains a concern. In the twenty-first century, more sophisticated detection of disease-causing organisms (pathogens) and even viral genetic material that have become part of the hosts' genetic material has reduced the possibility of xenozoonosis. Yet, xenotransplantation remains risky. The possibility remains that cross-species transfer of material could generate a hybrid pathogen capable of causing widespread illness.

The sacrifice of animals to sustain human health is controversial as well, especially to those who champion animal rights. Raising animals solely to be donors is repugnant to some people. In addition, Muslims and Jews do not consume pork for religious reasons, and this prohibition may cause them to refuse tissues or organs taken from pigs. On the whole, however, the use of animals in organ donations has met with relatively little resistance.

Maintenance of the xenotransplanted material is a more significant challenge. Research is underway to develop techniques for preventing immune rejection while at the same time maintaining an efficiently functioning immune system. In addition, pigs have been genetically changed in the laboratory so that their bodies create human tissues. These transgenic pigs may prove to be ideal sources of transplantable tissues and organs.

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[*See Also* **Vol. 1, Anti-Rejection Drugs; Vol. 1, Organ Transplants.**]

Biotechnology

Changing Life Through Science

Biotechnology

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Volume 2
Agriculture

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Agriculture

Description

Agriculture, or farming, is the oldest form of biotechnology. All the farmed plants and animals that we eat today, including cows, pigs, chickens, potatoes, wheat, corn, potatoes, tomatoes, rice, and many more, were developed thousands of years ago by farmers who practiced selective breeding of wild plants and animals. Modern science has adjusted this heritage of crop plants and livestock animals, but has not added anything really new to it.

In the last century, technology has changed agriculture in at least three basic ways. First, gasoline-powered machines have taken over most of the mechanical work. This has enabled a smaller number of people to grow food for all the rest. In the United States, 39 percent of the population worked in farming in 1900; by 2002, only one percent. This has made food much cheaper. It has also meant bankruptcy and distress for the small-farming population. Few people in our society know how to grow food or to care for the land.

Second, more food is being grown than ever before. This has been made possible by the use of gasoline-powered machines to plow, sow, harvest, and process crops. It has also depended on the creation of new varieties of plants, especially hybrid varieties (produced from two different plants or animals). These are plants that can be grown in vast monocultures (fields containing only one kind of plant), and they depend on fertilizers made from fossil fuel and on pesticides, including both herbicides (chemicals that kill unwanted plants) and insecticides (chemicals that kill insects). Also important has been the factory farming of animals, in which thousands of cattle, hogs, and chickens are raised in a single building or fenced-in set of fields.

Woman holding a bundle of barley on a farm in Bolivia. © *Caroline Penn/CORBIS.*

Third, agriculture has become more destructive than ever before. Soil is being lost rapidly around the world. In the United States, approximately two cubic yards (1.5 cubic meters) of soil are washed away for every cubic yard (0.7 cubic meter) of corn that is harvested. Soil, once lost, cannot be replaced, and when it is all gone, no amount of fertilizer can make crops grow.

Also, chemical fertilizing of crops and factory farming of animals has produced major pollution problems. In the United States, about 36 million cattle and 9 billion chickens, ducks, and turkeys are slaughtered yearly. Raising these animals produces vast amounts of excrement. Operators of the large, centralized operations where most of these animals are raised flush the waste into large open ponds called lagoons. The waste from the lagoons is

Pigs on a high-tech farm in Iowa. Building temperatures are controlled and feeding is automated. © *Macduff Everton/Corbis.*

sprayed on open ground to speed up its decay. Some waste seeps into the groundwater or runs off into streams and rivers as pollution. Some is used as fertilizer.

Agriculture has been further changed by biotechnology, especially genetic engineering. Starting in the 1990s, genetically modified crops have been grown in large amounts, especially soybeans and corn. Genetic engineering has been controversial. Some countries, such as Japan, some African countries, and most of Europe, restrict the growing or importation of genetically modified food. Although most government and corporate scientists agree that genetic engineering is safe, critics are worried that it might hurt human health or the environment. For example, artificial genes from genetically engineered crops might get into wild relatives of those plants and alter the balance of nature.

Scientific Foundations

Fossil fuels have shaped modern agriculture. The two fossil fuels directly important to agriculture are petroleum and natural gas. Petroleum is a fossil remnant of ancient forests that our civilization has been using with ever-increasing speed over the last century. Some experts believe that we may have already used more than half of what exists. Petroleum provides gasoline to fuel the tractors, harvesters, and processing machines that make our food. It also fuels the trucks, jet planes, and ships that transport food hundreds or thousands of miles to our tables. Modern agriculture also depends on nitrogen fertilizer, which is made using natural gas.

Genetic engineering of crops is done by adding genes to the deoxyribonucleic acid (DNA) in plant cells. DNA is a long, chain-like molecule of genetic information. All living things use DNA to pass on traits to their offspring. Cells use DNA as a recipe-book for making the complex molecules called proteins that they need throughout life. By changing plant DNA, scientists can change the proteins that the plants make in their cells. This can change the nutritional value of the plants, their resistance to certain chemicals, their production of certain chemicals, and other qualities.

Starting in the 1970s, an agricultural movement came into being that is intended to preserve soil, uses only natural fertilizers (such as decaying plant material and animal excrement), uses no chemical pesticides, and uses no genetically engineered plants or animals. The amount of organic food sold increased by about 20 percent per year from 1999 to 2006, a large increase. However, the amount of U.S. farmland being farmed organically was still less than one half of one percent in 2006.

Development

Originally, all human groups gathered wild plants and animals for food. Domestication of animals—the breeding of tame, useful varieties from wild varieties—began about 12,000 years ago in Asia and the Americas. The first domestic animal was probably the dog, bred from wolves. The oldest evidence for domestication of plants is about 10,000 years old.

The development of agriculture allowed civilizations centered around cities to arise, along with armies and empires. The plow was invented about 2,600 years ago in the Middle East, and is now used in almost all agriculture. Many horse- and mule-powered machines were invented during the nineteenth century, increasing the amount of food that each farmer could grow. In the industrialized world in the twentieth century, horses and mules were replaced by gasoline-powered tractors. With tractors, fewer farmers could grow more food than ever before. Unfortunately, they could also waste the soil faster than ever before. Most recently, biotechnology has changed agriculture by introducing antibiotics and genetically engineered organisms.

Cow Power!

When cattle manure rots, it gives off the gas methane. Methane is twenty times more potent as a greenhouse gas, ton for ton, as carbon dioxide (the main gas that is changing the world's weather). However, unlike carbon dioxide, methane can be burned as a fuel. Methane harvested from living sources like manure is called ''biogas.'' Biogas can be burned to run generators to make electricity. This not only turns the methane into carbon dioxide, which is not as bad a pollutant, but produces useful power. In Vermont, which has many dairy cows, electricity buyers have had the choice since 2006 of buying ''Cow Power.'' In the first year of the program, about 2,500 customers signed up to pay a little more for their electricity so that their whole electric bill could go toward buying electricity generated on Vermont farms from biogas. Cow Power is the first direct farm-to-consumer biogas power program in the country. Vermont hopes to make as much as five percent of its residential electricity from cow power by 2011.

Current Issues

The controversy over genetic engineering has already been mentioned. These are a few other issues that have to do with modern agriculture:

Antibiotic resistance. Antibiotics are substances that kill bacteria (a one-celled germ that can cause disease) and are used by doctors to treat bacterial infections in people. They are also given to cattle, chickens, and pigs to make them grow faster so that growers can make more money when they are slaughtered. As of 2001, U.S. growers were feeding about 25 million pounds (11 million kilograms) of antibiotics to livestock yearly, about eight times as much as was being given to human beings. Scientists warn that using antibiotics needlessly gives bacteria a chance to evolve resistance or immunity, producing resistant strains. These strains of bacteria cannot be treated with antibiotics when they attack people.

Nutrient runoff. Some of the fertilizer sprayed on fields is washed by rain into rivers, which run to the sea. There, the fertilizer feeds trillions of bacteria that use up the oxygen in the water. This kills off all other life, such as fish and shrimp, producing what is called a "dead zone." In the United States, the dead zone created in the Gulf of Mexico by the Mississippi and Atchafalaya Rivers, which together drain 40 percent of the country, is the size of the state of New Jersey and probably getting bigger every year.

Words to Know

Antibiotic: A compound produced by a microorganism that kills other microorganisms or retards their growth. Genes for antibiotic resistance are used as markers to indicate that successful gene transfer has occurred.

Biogas: Biogas is methane produced by rotting excrement or other biological sources. It can be burned as a fuel.

Dead zone: An area of ocean where nothing can live except bacteria that flourish on fertilizer from agricultural runoff.

Herbicide: A chemical substance used to kill weeds or undesirable plants.

Insecticide: A chemical that kills insects. Used in agriculture to kill insects that eat crops.

Methane: A gas resulting from the anaerobic digestion of organic matter by bacteria.

Organic farming: Farming that uses no artificial chemicals or genetically engineered plants or animals.

Pesticide: A chemical meant to kill plants or insects that hurt crops.

Cruelty to animals. The factory-farming system of raising animals for food has been criticized for its cruelty to animals. Chickens, for example, are grown in extremely crowded cages where they can never open their wings. Their beaks must be cut off so they will not peck each other to death. Pigs are kept in cages too small to turn around in. Defenders of factory farming say that its practices are efficient, profitable, and not as cruel as they are said to be.

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[*See Also* **Vol. 2, Biological Crop Rotation; Vol. 2, Breeding, Selective; Vol. 2, Genetically Engineered Animals; Vol. 1, Genetically Modified Foods; Vol. 2, Hybrid Plants; Vol. 2, Plant Grafting.**]

Alfalfa, Genetically Engineered

Description

Alfalfa is a tall, clover-like plant. Genetically engineered alfalfa is any alfalfa whose DNA (deoxyribonucleic acid, its genetic information) been changed in the laboratory.

After corn, soybeans, and wheat, alfalfa is the fourth-largest crop grown in the United States. It is used mostly to feed dairy cows and beef cattle, though it also is fed to pigs, sheep, and horses. Usually it is harvested and dried to make hay, which is then fed to the animals. The adult alfalfa plant is not eaten by people, but alfalfa sprouts (very young, tender alfalfa shoots) are eaten on sandwiches and salads.

There are several varieties, or breeds, of alfalfa, each of which grows best in a different climate. Until the 1980s, all breeds of crop plants, including alfalfa, were produced by breeding or artificial selection; that is, by using seed from plants with better characteristics, for example, bigger leaves or faster growth, to make the next generation. When bred in this way, each new generation became a little more useful as a crop. Today, some plant varieties—including some types of alfalfa—are being made not by selective breeding but by genetic engineering, the process of changing of the plant's DNA in the laboratory.

The only kind of genetically engineered alfalfa being sold as of 2006 is immune to a particular kind of weed-killer, or herbicide. This variety is called Roundup Ready® alfalfa. "Roundup" is the brand name of a the chemical called glyphosate, which is the mostly widely used weed killer in the world.

Scientific Foundations

Roundup Ready® breeds of alfalfa, corn, and soybeans have all been genetically engineered by the Monsanto company. A gene called

Hay is for . . . the Courts

In February 2006, farmers and environmentalists sued the U.S. Department of Agriculture over its 2005 approval of Roundup Ready alfalfa for commercial use in the United States. The people bringing the case against the government claim that the Department of Agriculture did not consider the effects of Roundup Ready alfalfa on the environment, the economy, or public health. An alfalfa farmer from South Dakota said that pollen from Roundup Ready alfalfa was sure to get into his crop and reduce its value. ‘‘The way this spreads so far and wide,’’ he said, ‘‘it will eliminate the conventional alfalfa industry. Monsanto will own the entire alfalfa industry.’’ Monsanto and the U.S. government offered no comment at the time the lawsuit was filed, but will have a chance to defend genetically engineered alfalfa later in 2006.

CP4 from a common soil bacterium (a very small, usually single-celled, organism) has been added to the DNA of these plants. A gene is a short piece of DNA that acts like a recipe for a certain chemical, telling the cell how to make that chemical. Plants that have the CP4 gene in their DNA are immune to glyphosate. Farmers and gardeners can put this herbicide on plots growing Roundup Ready genetically engineered plants and kill only the weeds.

There are several ways to change DNA. One method is to shoot very small metal bullets coated with thousands of copies of the new gene through a cell. Some of the DNA stays in the cell and is taken by the cell to its center (nucleus), where it is can get added to the DNA already there. Monsanto’s genetically engineered alfalfa was made by this method, which is usually called the bioballistic or particle acceleration method.

Development

The knowledge and machines needed to genetically engineer plants and animals were developed over many years starting in the 1950s. By the 1980s, it was possible to begin genetically engineering organisms. Test crops of genetically engineered plants were first grown in the 1980s. Starting in 1997, Monsanto and a company called Forage Genetics began working together to make several kinds of genetically engineered alfalfa. By 1998, an early variety of Roundup Ready alfalfa was being grown in test fields. In 2005, the U.S. Department of Agriculture (part of the federal government) gave official approval for Roundup Ready alfalfa to be sold and grown in the United States.

Words to Know

DNA: A double-helix shaped molecule inside cells that carries the genetic information.	**Herbicide:** A chemical substance used to kill weeds or undesirable plants.
Glyphosate: A weed-killing chemical; the world's most-used herbicide.	

Current Issues

Many people debate the question of whether it is wise to grow genetically engineered crops. Most scientists believe that such crops are safe and will benefit the world. A minority of scientists disagree, as do some citizens in the United States, Europe, Africa, Asia, and Latin America. Organic farmers, who raise all their plants and animals without using artificial chemicals, and environmental groups oppose the use of genetically engineered plants.

People in favor of growing genetically engineered alfalfa argue that it is safe and has been shown to boost production. They point to studies paid for by Monsanto that show that Roundup Ready alfalfa makes higher-quality feed because fewer weeds are mixed with the alfalfa. Dairy cows fed Roundup Ready alfalfa produced almost 8 percent more milk than cows fed regular alfalfa (acre for acre of alfalfa planted). Monstanto, which seeks to make money by selling both Roundup Ready alfalfa seeds and Roundup to farmers, also states that farmers can raise more alfalfa per acre using their products. If the cost of buying the genetically engineered seed and extra herbicide is less than the extra income the farmer makes by growing more alfalfa per acre, then a farmer would make more money per acre by raising Roundup Ready alfalfa.

Opponents of genetically engineered alfalfa argue that pollen from Roundup Ready alfalfa fields spreads to the alfalfa crops of organic farmers, who do not want to raise genetically engineered alfalfa. Crops polluted in this way cannot be sold at the higher price commanded by organic crops. Opponents also argue that increased use of glyphosate—which is what Roundup Ready alfalfa is designed to make possible—will cause glyphosate-resistant weeds to evolve more quickly. This will force farmers to use more glyphosate, which adds to their production costs, and eventually glyphosate will become useless, potentially forcing farmers to use more toxic chemicals. Opponents of Roundup Ready alfalfa say that Arkansas farmers already spend about $500 million per year fighting glyphosate-resistant weeds.

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[*See Also* **Vol. 2, Corn, Genetically Engineered; Vol. 2, Cotton, Genetically Engineered; Vol. 2, Rice, Genetically Engineered; Vol. 2, Transgenic Plants.**]

Animal Cloning

Description

Cloning is a process that creates an animal with the same genetic material as another. The new animal is an almost exact copy of the original. It is possible to clone many kinds of animals, but the process is complex and must be performed in a laboratory.

There are several reasons to clone an animal. One is to create animals that can produce products useful for human health, such as milk that contains medicine or antibodies (proteins produced by the immune system that fight off infection). A second reason is to make animals with desirable traits, such as tender meat or soft wool. Another use for animal cloning is to create organs that can be transplanted into humans. Using animal organs in humans is called xenotransplantation. Cloned animals can provide models to help scientists better understand aging and diseases in humans. Animals can be cloned to save a species that is nearing extinction, or to (in a sense) bring back a deceased pet.

Scientific Foundations

Cells are the building blocks of an animal's body. All parts of an animal, including skin, hair, and bone are made of cells. In the nucleus (the part of the cell containing the information needed for cell reproduction) of each cell is deoxyribonucleic acid (DNA). DNA, also referred to as genes, contains instructions that determine the physical traits of a living thing. Animals, just like humans, inherit half of their DNA from their mother, and half from their father.

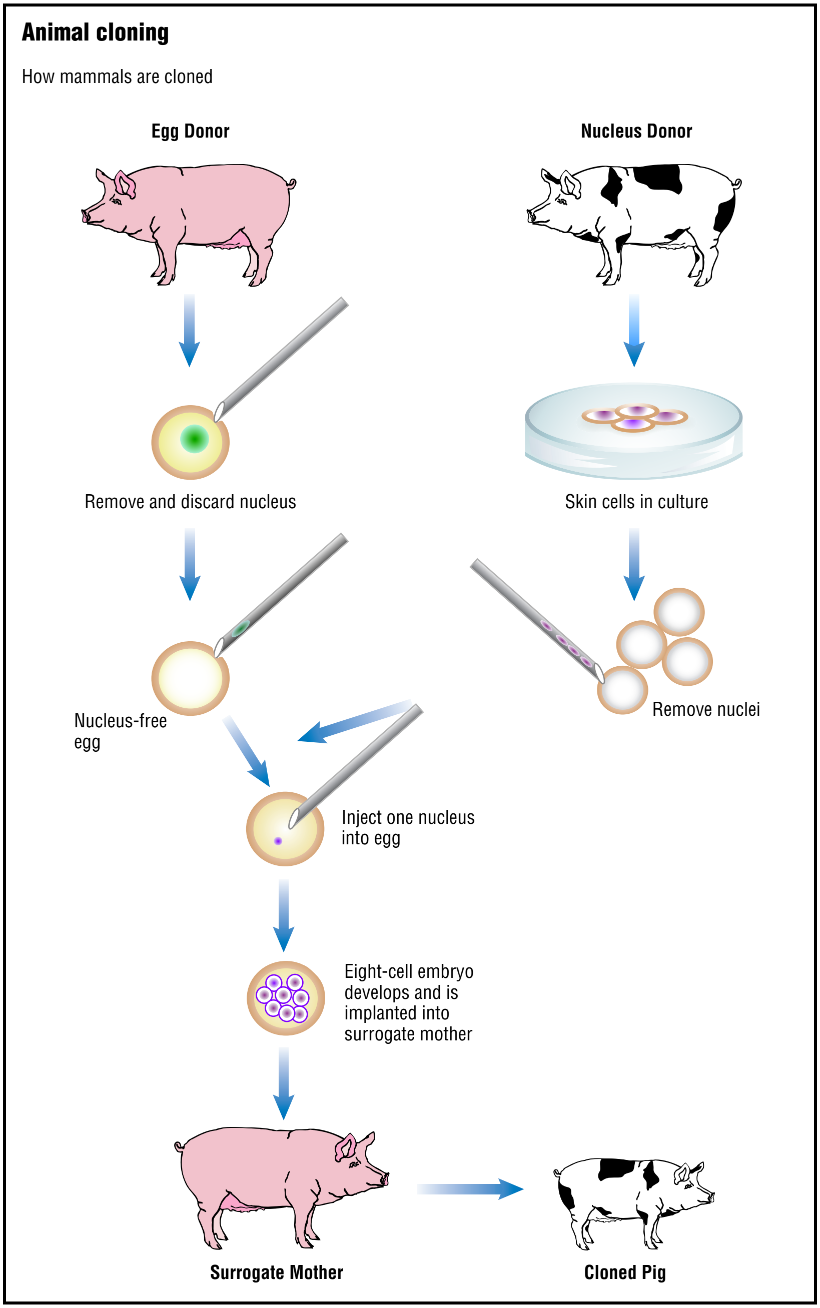
In nature, when a sperm from a male animal fertilizes an egg from a female, the fertilized egg begins to divide into multiple cells. After a few days, it becomes an embryo (an animal or human in the earliest

The first adult mammal to be cloned, a sheep named Dolly. *AP/Wide World Photos.*

stages of development). That embryo implants in the female's uterus (a hollow organ in the female's body in which the fetus grows). Sometimes a fertilized egg divides into two separate embryos that are genetically the same. These are called identical twins.

When scientists clone an animal, they put the nucleus from an adult animal cell into an unfertilized egg that has had its own nucleus removed. They stimulate the egg and genetic material with an electric shock, causing them to combine and begin dividing.

How mammals are cloned. An egg donor is implanted with the nucleus of a donor cell. After the egg develops, it becomes a clone of the nucleus donor. *Illustration by GGS Inc.*


Animal cloning
How mammals are cloned
Egg Donor
Nucleus Donor
Remove and discard nucleus
Skin cells in culture
Nucleus-free egg
Remove nuclei
Inject one nucleus into egg
Eight-cell embryo develops and is implanted into surrogate mother
Surrogate Mother
Cloned Pig

The embryo that results from this division is implanted into a surrogate (a female that carries another animal's genetic offspring) animal of the same species.

A Sheep's Life

Dolly was born on July 5, 1996 at the Roslin Institute in Scotland. By all appearances, she looked and acted like a normal sheep, but she was not normal. She was a clone, the first cloned sheep successfully born.

Dolly grew up and gave birth to several lambs, but she suffered from premature aging. This disease caused her body to have symptoms of old age while she was still young. She eventually developed arthritis (a disease causing swelling and pain in the joints) and lung disease. Scientists believed her health problems may have been related to the cloning process. Dolly was put to sleep in February 2003 at the age of six.

Development

The first animal cloning experiments were done with frogs in the 1970s. The experiments were not successful because the cloned frogs only lived to the tadpole stage. Cloning experiments continued over the next two decades. In 1995, scientists at the Roslin Institute in Scotland cloned two lambs named Megan and Morag. They created these clones by replacing the nuclei of ordinary sheep eggs with very early embryos. The scientists coaxed new cells to divide, and then implanted the resulting embryos into female surrogates.

In 1997, scientists at the Roslin Institute used a new technology, called somatic cell nuclear transfer (SCNT), to clone Dolly the sheep. A somatic cell is an adult cell of an animal, but not a sperm or egg cell. Scientists inject the nucleus from a somatic cell of the animal they want to clone into an unfertilized egg with the nucleus removed. To create Dolly, scientists used the nucleus of an udder (the milk-secreting organ of a cow, sheep, or goat) cell from an adult female sheep. The scientists let the egg divide for a few days and implanted it into a ewe (female sheep). This ewe gave birth to Dolly, who was genetically unrelated to her. Since Dolly was cloned, scientists have cloned mice, rabbits, pigs, donkeys, horses, and other mammals.

An animal clone is almost, but not quite, identical to the animal that donated its DNA. Although the egg into which the DNA is inserted has no nucleus, some genetic material remains in the mitochondria (structures that provide energy for the cell) contained in the cell body.

Current Issues

Cloning an animal is not easy. Scientists made 276 attempts before creating Dolly. Only one percent of the embryos implanted in surrogate mothers produce live offspring. Often, clones do not

Words to Know

Antibodies: Molecules created by the immune system in response to the presence of an antigen (a foreign substance or particle). It marks foreign microorganisms in the body for destruction by other immune cells.

Arthritis: Inflammation of the joints.

Cloning: The production of multiple genetically identical cells or organisms.

Deoxyribonucleic acid (DNA): The double-helix shaped molecule that serves as the carrier of genetic information for humans and most organisms.

Embryo: A stage in development after fertilization.

Mitochondria: An organelle that specializes in ATP formation, the ''powerhouse'' of the cell.

Nucleus: A compartment in the cell which is enclosed by a membrane and which contains its genetic information.

Somatic cell: Cells that are part of the body but are not in the germline (able to pass their DNA on to future generations). Any type of cell in the body that is not a sperm or egg cell.

Surrogate: A female who carries another animal's genetic offspring.

Udder: The milk-secreting organ of a cow, sheep, or goat.

Uterus: Organ in female mammals in which the embryo and fetus grow to maturity.

Xenotransplantation: Transplantation of tissue or an organ from one species to another, for example from pig to human.

live long after birth. Many of those that survive are deformed (abnormally shaped) or have other genetic abnormalities. Scientists have been trying to improve the cloning technique to gain better results.

There are also concerns whether animal cloning is moral (right according to religious views) and safe. Some groups worry about the safety of milk and food from cloned animals. In 2006, the Federal Department of Agriculture (FDA) required that no milk or meat produced from cloned animals could be used for food in the United States. Some groups of people feel that tampering with nature by cloning is wrong. They also fear that cloning animals could lead to cloning people.

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[*See Also* **Vol. 1, Human Cloning; Vol. 2, Genetic Engineering; Vol. 2, Genetically Engineered Animals; Vol. 1, Genetically Modified Foods; Vol. 1, Nuclear Transfer; Vol. 1, Organ Transplants; Vol. 2, Transgenic Animals; Vol. 1, Xenotransplantation.**]

Apiculture (Beekeeping)

Description

Beekeeping, what is formally called apiculture, involves maintaining colonies of bees in hives for the production of honey and beeswax, and for the pollination of agricultural crops. A variety of bee species may be raised including dwarf honey bees, European honey bees, Indian honey bees, and stingless bees.

Groups of hives are called apiaries, and a beekeeper is called either an apiculturist or an apiarist. To prevent bee stings while working around them, beekeepers wear light, protective clothing including hats, gloves, pants, shirts, and veils about their faces. The honey produced by the bees, which is removed by beekeepers, is used to sweeten food, while the beeswax is used in such products as cosmetics, candies, candles, and waterproofing and protective mixtures.

As of 2005, the United States Department of Agriculture (USDA) estimated that between 139,600 and 212,000 beekeepers worked in the United States. The USDA considers a commercial beekeeper is anyone that keeps over 300 bee colonies. These commercial operations, which number about 1,600 in the United States, produce about 60 percent of the country's honey. The average U.S. citizen consumes about 1.3 pounds (0.6 kilograms) of honey each year.

Bees also pollinate about one-fourth of all agricultural crops produced in the United States. Some of the crops that use bee pollination include apples, apricots, blueberries, cherries, pears, strawberries, watermelons, broccoli, cabbage, carrots, cucumbers, onions, and squash.

Scientific Foundations

Bees are winged insects with feathery body hairs that feed on flowers. They have three body parts: head, thorax, and abdomen. Bees have one pair of compound eyes, one pair of antennae, three pairs of legs, and two pairs of wings. They range in size from 0.08 inch to 1.6 inches (2 millimeters to 40 millimeters). Bees come in various colors such as black, gray, yellow, red, and metallic green and blue. Some female bees have stingers for defense.

Bees eat pollen and nectar from flowers. Different bee species have different nesting habits. Some females build a nest alone. These females place pollen in a nest, deposit an egg on top, seal the nest, and then leave to build another nest. Other females live in small colonies where several females build a nest together and then divide the nest into their own cells. Other females build a nest with the help of younger females. Still other females live in large colonies where each bee has specific duties. Males usually do not participate in nest building, but only mate with females.

Development

The keeping of bees probably originated several thousand years ago in the Middle East or Africa. Today, bees are scattered throughout

Bees are 'Busy as Bees' Producing Honey

As of 2005, according to the U.S. Department of Agriculture, there are over 2.4 million colonies of honey bees in the United States. Bees fly about 55,000 miles (88,500 kilometers) while stopping at about two million flowers to make 1 pound (0.45 kilogram) of honey. The top states producing honey from bees (in order of production) are: North Dakota, California, South Dakota, Florida, and Minnesota. Internationally, China, the United States, Argentina, Turkey, Ukraine, Mexico, and Russia are the leading honey producers. China, the world's leading producer, makes more than 309 million pounds (140,000 metric tons) of honey, while the United States produces over 196 million pounds (89,000 metric tons) of honey. The countries that import the most honey each year are Germany, the United States, Japan, and the United Kingdom.

the world, living everywhere except in polar areas, in very high altitudes, and on some small islands. Most bees like warm and arid or semiarid areas. There are around 20,000 species of bees.

Early harvesting of honey and beeswax involved the killing the bees living in the hives. In 1851, American apiarist Lorenzo Lorraine Langstroth (1810–1895) discovered how bees build their hives—what he called the principle of bee space. Langstroth found that bees built hives with about 0.23 inches (0.6 centimeters) of space between wax combs. With this knowledge, beekeepers made artificial hives so that each comb could remain separated from neighboring combs. Consequently, individual combs could be removed from a hive in order to harvest honey and wax without killing the bees.

Current Issues

Beekeepers face at least two serious problems in maintaining their hives. Many diseases occur when bees are placed in hives more crowded than their natural environment. Consequently, the bees are more likely to die. Fewer bees means fewer colonies of bees, which results in less honey produced and less crops pollinated. Also, the expensive equipment used for beekeeping can easily become contaminated. In many cases, such equipment must be destroyed when contamination cannot be removed. Because of bee diseases and equipment problems, it costs beekeepers more to do their jobs.

In the United States, Africanized honey bees have been identified as a public health concern. (Also called killer bees, these bees are African bees raised for research in South America that have escaped

Words to Know

Nectar:	The sweet liquid that flowering plants make to attract insects and small birds, which help to pollinate those plants.
Pollen:	Cells of a plant that contain male DNA.
Pollination:	Movement of pollen from the male reproductive organ to the female reproductive organ, usually followed by fertilization.
Thorax:	The area just below the head and neck; the chest.

and spread north.) However, since 1990, the number of bee-related deaths in the United States has stayed about the same each year even though more people are stung. More bee-sting deaths have occurred, however, in various countries of Central and South American, especially in Mexico and Argentina. Because of their aggressive behavior, Africanized honey bees frequently attack other bees and humans that they think are invaders. Africanized honey bees were first reported in Texas in the early 1990s. So far, these bees have not seriously harmed beekeepers in the southwestern states. However, beekeepers in Latin American countries have been financially hurt by Africanized honey bees because of the different method of beekeeping that they use.

As habitats of bees are destroyed or changed by human activities, fewer bees and fewer bee species remain. Because bees pollinate so many different wild and agricultural crops and help to produce so many products, their value is important to the health of humans and other living things.

Nectar from some genetically modified crops (rapeseed, for example) is especially attractive to some bees. Scientists are studying the honey made from the pollen of genetically-modified crops to evaluate its safety for humans and its impact on bees.

■ ■ ■

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[*See Also* **Vol. 2, Agriculture; Vol. 2, Breeding, Selective; Vol. 3, Cosmetics.**]

Aquaculture

Description

The farming of aquatic organisms (plants and animals that live in water) in controlled, artificially made bodies of water is called aquaculture. Commonly raised aquaculture fish include Atlantic salmon, channel catfish, tilapia, bait and ornamental fish, crawfish, and rainbow trout. Shellfish widely farm-raised include clams, mussels, and oysters. Aquaculture is different from the traditional method of fishing called capture fishing, which uses several means—hooked fishing line, nets, or traps—to catch aquatic organisms in their natural environment.

Aquaculture farmers place juvenile organisms (called seeds) in the fresh, brackish, or salt waters of an artificially constructed enclosure, such as a specially dug pond. The water is fertilized and the young organisms are fed in order to produce large numbers of adult organisms as quickly as possible. Aquatic farmers make sure the water quality remains good in order to produce the largest and highest number of organisms. Because aquaculture farmers actively raise fish in captivity, aquaculture is more efficient than capture fishing, in which fish remain in the wild until caught.

Scientific Foundations

Virtually all fish use gills to "breathe" and are classified as vertebrates, meaning they have backbones. There are about 25,000 known species of fish with 250 new species on average being discovered each year. They come in many sizes, from sharks that reach 40 feet (12 meters) in length to Stout Infantfish that are only about 0.3 inches (0.8 centimeters) long.

The fish's head is connected to a spinal column; there is a tail, along with several limbs. Most fish have fins (a type of limb) to help them swim. Scales are also found on most fish to protect them from

Worker at a fish farm catching salmon for harvest. © *Natalie Fobes/Corbis.*

predators. Their sleek bodies, pointed noses (called snouts) and posteriors, and wide tails allow most fish to move easily through the water. However, some fish are shaped similar to snakes. Still others are flat or boxlike in shape. These fish do not swim fast, but have colorings or other features that make them difficult to see in their lives around coral reefs, in hollow cavities and caves, or on the floors of oceans.

Development

Aquaculture has been practiced for at least 4,000 years, mostly in such countries as China, Egypt, and Italy. Records have shown that Chinese farmers raised carp around 2000 BCE. Aquaculture spread through Europe and across Asia where fish were captured from rivers and placed into ponds and other water bodies until they were ready to be eaten. By the thirteenth century, France was raising mollusks and Japan was farming oysters. Two centuries later, aquaculture farmers in Europe were adding manure to water (what was called pond fertilization) to help grow tiny animals and plants (called plankton) that were fed to fish.

Genetically Altering Fish

The possibility of genetically altered fish is causing much discussion worldwide. By inserting extra genes into fish, aquaculture farmers are hoping to create fish that grow faster and fight off disease better than wild fish. Researchers have found at least eleven fish species (including salmon, flounder, and trout) that could be altered genetically so that they will grow faster than they normally do in nature. Almost every kind of plant or animal that humans raise for food has been changed over time using traditional breeding techniques. Fish, on the other hand, have been mostly harvested as they exist in the wild. So far, no fish have been genetically altered and sold as food for humans except for some fish in China.

In 1853, rainbow trout were first commercially raised in aquatic farms within the United States. In the 1870s, the U.S. created a system of federal and state hatcheries to raise fish in fresh water that later matured in salt water. Some of these fish stocked public and private waters for game fishing. However, only since the twentieth century, as the world's population rapidly grew and as people ate more fish, did aquaculture become important for feeding the world's population. Trout were first farmed commercially in the western parts of the United States during the 1950s. Later that decade, shrimp hatcheries and farms were established in Japan. In the 1960s, the salmon industry was established in Europe and the channel-catfish industry was created in the United States.

Current Issues

As of 2004 aquaculture accounted for about forty percent of all seafood eaten by humans, according to the Food and Agriculture Organization of the United Nations (FAO). Since 1970, aquaculture farming worldwide has increased about 9 percent each year, according to the World Bank. The rapid growth of the aquaculture industry, however, raises issues that affect populations worldwide.

Fish waste is mostly feces and nitrogen byproducts. People living near aquaculture farms have been concerned about the amount of these wastes in their environment. However, to grow the best and most numerous fish, aquaculture farmers work to prevent excess wastes. Quality-conscious fish farmers use a variety of monitoring devices and removal equipment to detect and remove waste build-up as quickly as possible.

Words to Know

Antibiotics: Drugs that target and kill bacteria, but are ineffective against viruses.

Brackish: A mixture of fresh and salt water.

Feces: Solid waste of a living body.

Polychlorinated biphenyls (PCBs): A compound of biphenyl and chlorine that is considered a hazardous pollutant.

Vaccine: A product that produces immunity by inducing the body to form antibodies against a particular agent. Usually made from dead or weakened bacteria or viruses, vaccines cause an immune system response that makes the person immune to (safe from) a certain disease.

The antibiotics given to fish to treat diseases is cause for concern too. If fish are given antibiotics too often or at high doses, the fish may develop resistance to them. Also, the fish treated in this way may not be as healthy to eat. Disease prevention is the best way to reduce the need for antibiotics. Good water quality and safe farming practices, such as lower numbers of fish stock and high quality fish feed, are ways to avoid the need for antibiotics. When available, vaccines have also been found useful in stopping disease.

Some individuals and organizations are concerned that farm-raised fish may damage wild fish populations, especially if genetically modified fish breed with wild stock. Issues are also raised concerning humans eating genetically modified fish. As of 2006, no genetically modified fish products are allowed to be eaten by the public in the United States. Strict state and federal regulations are maintained in the United States regarding the uses of genetically modified organisms in aquaculture.

Polychlorinated biphenyls (PCBs)—chemicals banned in the United States in the late 1970s—have been found to contaminate most of the planet. As of 2005, the levels of PCBs in wild and farmed salmon, for example, are equal. According to the U.S. Food and Drug Administration (FDA) and many international health organizations, PCBs pose no health risk to most consumers. These organizations state that it is easier to control levels of PCBs in farm-raised fish that it is in wild fish.

Mercury contamination of fish and seafood has been an issue for a number of years. Small fish take in mercury (actually methylmercury), and larger fish then eat these smaller fish, and so on. Thus, larger fish near the top of the aquatic food chain have a higher likelihood of being contaminated by mercury and may pose a threat to human health if eaten. Mercury poisoning has been associated with problems in humans such as birth defects, memory loss, and heart disease. In 2005 mercury levels in fish were found to range from slightly reduced to about equal when compared to levels in the 1970s. Farmers who raise fish are better able to control mercury levels, since they can control what the fish eat and environments in which the fish are raised.

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[*See Also* **Vol. 2, Genetically Engineered Animals; Vol. 1, Genetically Modified Foods.**]

Beer-Making

Description

Beer is an alcoholic beverage made from grain (usually barley), water, hops (dried flowers of a vine in the mulberry plant family), and yeast (a type of single-celled fungus). It is made by one of the oldest biotechnology processes—fermentation. This process gives beer its alcohol and carbonation (bubbling caused by the gas carbon dioxide). Enzymes convert the starch in the grain to sugars, which are fermented by the yeast to make alcohol.

Scientific Foundations

Fermentation is a chemical change that produces energy through the anaerobic breakdown of simple sugars. An anaerobic process is one that does not need oxygen. Fermentation usually refers to the conversion of sugar to alcohol by yeast. This process is used to make beer and wine.

Enzyme reactions in the yeast break apart the chains of sugar molecules to produce ethyl alcohol (a drinkable alcohol, also called ethanol, which is produced by the fermentation of sugar) and carbon dioxide (a colorless, odorless gas made up of carbon and oxygen). An enzyme is a biological catalyst, a substance that speeds up a chemical reaction. The yeast continues to grow and multiply, until the concentration of alcohol becomes toxic and kills the yeast, stopping the fermentation process.

Development

The history of brewing beer dates back about 6,000 years to the Middle East. Archaeologists have unearthed 3,800-year-old Babylonian tablets containing a recipe for beer. The ancient Egyptians

Beer vats at a brewery in the Czech Republic. *Liba Taylor/ Corbis-Bettman.*

and Mesopotamians also made beer from the grain they harvested, according to historical records. Because grain cannot be squeezed to release the juice, as can grapes for wine, it had to be made into a

Strange Brews

Barley, hops, water, and yeast are the main ingredients in beer. Change the process a bit, and the results are different types of beer: ales, stouts, lagers, or porters. Some enterprising beer makers have added a few extra ingredients, including apples and berries, ginger and other roots, and nuts to spice up their brews.

Boston Brewing Company adds chocolate to make a beer that tastes almost like dessert. The Dogfish Head Craft Brewery in Delaware has created a sweet ale made with cinnamon, nutmeg, and brown sugar. Many other breweries add their own signature flavors to create highly unusual beers. These additions are not anything new, however. During Colonial days, when adequate barley supplies were often lacking, people added all sorts of fermentable foods, from pumpkins to parsnips, to their brewing beer.

liquid by soaking it in water. This led to the development of a fermentation process.

At first, women were the primary brewers of beer, because they were also in charge of making bread and other foods for their families to eat. Until the Middle Ages (c. 500–c. 1500), beer was mainly brewed in homes. In the fourteenth and fifteenth centuries, monasteries (religious communities in which monks live) and pubs began brewing beer as well. The monasteries improved upon the brewing process. They added hops for flavor and as a preservative, an ingredient added to keep food and beverages from spoiling.

The invention of steam power and cooling processes during the Industrial Revolution of the eighteenth and nineteenth centuries further improved beer-making. Artificial cooling allowed beer-makers to brew even in the warm summer months. Bottled beer was introduced in 1875 and canned beer first appeared in 1935.

The process of making beer has changed little in thousands of years. In addition to the four basic ingredients used to make beer, water, malted grain (usually barley), hops, and yeast, other ingredients can be added to give the beer a specific flavor.

The brewing process starts by malting the barley. The barley is soaked in water, drained, and left to sit at about 60 degrees Fahrenheit (15.5 degrees Celcius) for a few days. This causes the husk to open. The barley at this stage is called green malt. During the malting process, enzymes in the barley convert starches, complex sugars, into simple sugars to feed the growing plant. The green malt is warmed to dry it.

Words to Know

Anaerobic: Describes biological processes that take place in the absence of oxygen.

Carbonation: Bubbling in a liquid caused by carbon dioxide.

Carbon dioxide: A heavy, colorless gas that dissolves in water.

Ethyl alcohol: A drinkable alcohol, also called ethanol, which is produced by the fermentation of sugar.

Fermentation: The process of breaking down sugar without oxygen into simpler substances, commonly alcohol and carbon dioxide.

Monastery: A religious community in which monks live.

Preservative: A compound added to food products to ensure they do not spoil.

Wort: The sugar-water solution made when malted barley is steeped in water and its complex sugars break down into simple sugars.

Yeast: A microorganism of the fungus family that promotes alcoholic fermentation, and is also used as a leavening (an agent that makes dough rise) in baking.

Next the malted barley goes through the mash process. First, the barley is crushed between rollers into a coarse powder. The crushed barley moves to a machine where it is steeped in hot water. The hot water activates enzymes in the malted barley. These enzymes break down the starch in the grain by cutting the long chains of the starch molecules to produce simple sugar molecules with shorter chains. During the fermentation phase the yeast is able to digest, or break down, these simple sugar molecules. The liquid drained out at the end of the mash process is thick and sweet because it contains a lot of sugar.

The liquid from the mash is put into a big machine called a brew kettle. It is brought to a boil, and then hops are added. The hops contain acids that add bitterness to the beer. This mixture is called wort. It continues to boil to remove some of the bitterness of the hops. Then, the grains are filtered out of the mixture.

Next is the fermentation process. The wort is allowed to cool and is moved to a fermenting tank. The yeast is added. The yeast converts the simple sugar into ethanol and carbon dioxide. The carbon dioxide gives beer its carbonation. There are two types of yeast: top-fermenting yeast and bottom-fermenting yeast. Top-fermenting yeast rises to the surface of the tank during fermentation, and bottom-fermenting yeast stays on the tank's bottom and ferments more slowly. After fermentation, the beer may be filtered again to remove any yeast that remains. Then the beer may be put into another tank to age. Finally, it is bottled.

Current Issues

Beer-making can be considered the beginning of biotechnology. Although the basic biological processes have remained virtually unchanged over the years, advances in biotechnology have changed the way some beer makers now practice their craft. For example, scientists have genetically engineered barley with a bacterial enzyme that stays active for much longer during the heating process. Genetic engineering involves taking a gene for a particular trait from one organism, and inserting it into the cells of another organism. Genetically engineered bacteria and yeast have been used to make beer less bitter, and to make "light" beers that contain less sugar (and fewer calories). Although many beer brewers view these as significant advances, some people worry that genetically modified foods could be dangerous, producing unknown effects on human health.

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[*See Also* **Vol. 2, Bread-Making; Vol. 3, Enzymes, Industrial; Vol. 3, Ethanol; Vol. 3, Fermentation, Industrial; Vol. 2, Wine-Making.**]

Biofuels, Liquid

Description

Biofuels are fuels that use the energy stored in living organisms to power automobiles and to provide energy for a number of other uses. Liquid biofuels include the alcohol fuel called ethanol as well as biodiesel, which is produced from vegetable oils. The raw materials used to produce these fuels are called biomass. Biomass can include trees; leftover crops, such as soybeans and corn; animal wastes; or the waste products of certain industries, such as woodchips from the logging industry, pulp from the paper industry, and food waste from the food processing industry.

Because biofuels are made from organic products, they are easily renewable, which means that their sources can regenerate relatively quickly. Fossil fuels, such as oil and gas, which are used most often today, are nonrenewable energy sources. They take thousands of years to regenerate and could eventually run out. Biofuels also burn more cleanly than fossil fuels to produce fewer pollutants.

Scientific Foundations

Plants use energy from the Sun to convert water and carbon dioxide into sugars that they use as food. This process is called photosynthesis. Some plants, such as corn, store the sugars in chains called starches. To make biofuel, those starches are converted into sugars, which are then fermented to make alcohol (ethanol). During the fermentation process, yeast (a one-celled type of fungus) is added to the sugar. The yeast eats the sugar and produces ethanol and carbon dioxide (the nontoxic gas used to make sodas “bubbly”).

TOSHIBA
DMFC
Powered by TOSHIBA

A digital audio player powered by a direct methanol fuel cell. © *Issei Kato/ Reuters/Corbis.*

Development

During the late 1800s, ethanol was used to fuel lamps. When Henry Ford (1863–1947) rolled out his Model T car in 1908, it was designed to run on ethanol. During Prohibition (1920–33), when the government banned the use of alcoholic beverages, ethanol was also banned because the government considered it a type of alcohol. Prohibition ended in 1933, but low prices helped fuel the popularity of petroleum-based gasoline, which eventually took over as the leading fuel for transportation.

Ethanol made a comeback in the 1970s, when the Middle East oil crisis sent gasoline prices soaring, and people began looking for alternative fuel sources. Then the Clean Air Act of 1990 set limits on the amount of pollution that vehicles could release. Car manufacturers introduced flexible fuel vehicles, which run on a blend of ethanol and gasoline. When added to gas, ethanol makes the fuel burn more cleanly and efficiently. The number of vehicles running on ethanol and other alternative fuel sources continued to increase in the late 1990s and early 2000s.

Biofuels are produced in facilities called biorefineries. In these refineries, corn and other grains containing starches—long chains made up of molecules of the sugar called glucose—are first heated and then enzymes (substances that speed a chemical reaction) are added. The enzymes break down the starches to produce simple

Cleaner Burning Fuels

One of the biggest problems with burning fossil fuels such as oil and gasoline is that they pollute the environment and contribute to the problem of global warming. Fossil fuels are carbon-based. When they burn in the air, their carbon atoms combine with oxygen to form carbon dioxide. Carbon dioxide is a greenhouse gas. Greenhouse gases trap energy from the Sun in the atmosphere and can increase global temperatures. Burning ethanol does not lead to the production of carbon dioxide in the air, and mixing ethanol with gasoline can actually reduce the production of greenhouse gases.

sugars. Then yeast is added to the sugar. The yeast consumes the sugar and produces ethanol and carbon dioxide. The ethanol is distilled (to purify a liquid by heating) to make it ready for use.

Ethanol also can be made from cellulose-based biomass, such as trees and grass. Cellulose (found in plant cell walls) is made up of chains of sugar molecules. Enzymes are added to break up the chains, in order to produce simple sugars. The sugars are then fermented using yeast to produce alcohol.

Biodiesel is made using the oil from plants such as rapeseed (canola), soybeans, and sunflowers. The oil is extracted from the plants and then mixed with an acid (a strong, sour liquid). Then a chemical is used to separate out the biodiesel from the mixture. Finally, the biodiesel is purified.

Current Issues

Many people think that biofuels are more environmentally friendly than fossil fuels. Unlike fossil fuels, biofuels are renewable. Also, biofuels burn more cleanly than fossil fuels. They release less carbon dioxide (a gas that contributes to global warming), sulfur dioxide (a poisonous gas), and other pollutants into the atmosphere.

How Do You Spell Biodiesel?

In 2006, biodiesel fuel reached another milestone on its road to public acceptance. For the first time the word ‘‘biodiesel’’ appears in the *Merriam-Webster Collegiate Dictionary*, where it is defined as ‘‘a fuel that is similar to diesel fuel and is derived from usually vegetable sources (as soybean oil).’’ Using this measure of success, biodiesel is well on its way to becoming a household word.

Words to Know

Biodiesel: An environmentally friendly fuel made from a combination of plant and animal fat. It can be safely mixed with petro diesel.

Biomass: Any biological material used to produce energy.

Carbon dioxide: A heavy, colorless gas that dissolves in water.

Catalyst: Any agent that accelerates a chemical reaction without entering the reaction or being changed by it.

Cellulose: The main ingredient of plant tissue and fiber.

Deforestation: Removal of trees from an area.

Distill: To collecting and condensing the vapor from a boiling solution. Each distinct, volatile chemical compound boils off individually at a specific temperature, so distillation is a way of purifying the volatile compounds in a mixture.

Enzyme: A protein that helps control the rate or speed of chemical reactions in the cell.

Ethanol: A form of alcohol.

Greenhouse gas: A gas that contributes to the warming of the Earth's atmosphere. Examples include carbon dioxide, HCFCs, CFCs, and HFCs.

Landfill: An area of land that is used to dispose of solid waste and garbage.

Organic: A term used to describe molecules containing carbon atoms.

Photosynthesis: Biological conversion of light energy into chemical energy by plants.

Yeast: A microorganism of the fungus family that promotes alcoholic fermentation, and is also used as a leavening (an agent that makes dough rise) in baking.

Biofuels can also help the environment by using wastes that would otherwise be dumped in landfills (large outdoor garbage piles). And many experts say that using more biofuels will help reduce America's dependence on foreign oil.

Biofuels are more expensive to produce than fossil fuels and this is why they are not used more widely. In addition, energy companies lack efficient methods for producing biofuels. Since liquid biofuels are made using agricultural products, there is some concern that obtaining the biomass needed for their production could overuse the land or lead to deforestation (destroying forest lands).

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[*See Also* **Vol. 2, Agriculture; Vol. 2, Biofuels, Solid; Vol. 3, Enzymes, Industrial; Vol. 3, Ethanol; Vol. 3, Fermentation, Industrial; Vol. 3, Oil-Seed Crops.**]

Biofuels, Solid

Description

Biofuels are made from biomass. Biomass is natural material that can be used for energy. Types of biomass include dead trees, grasses, wood chips, animal wastes, plant- and animal-based garbage (such as food scraps), and leftover agricultural crops such as soybeans and corn. Biofuels can be used as a solid or converted into liquid or gas form.

Scientific Foundations

Biomass contains energy that has been stored from the sun. Plants use energy from the sun to convert water and carbon dioxide into a form that the plant use as energy, called carbohydrates. This process is called photosynthesis. The chemical energy gets stored in the plant, and when the plant is burned, the energy is released. This is why, for example, firewood burned in a fireplace can be used to heat a house.

Biomass can be used for energy in several different ways. Solid biofuels can be burned to produce heat, which can, in turn, be used to generate electricity. Biomass can also be converted through fermentation (the conversion of sugar into alcohol, typically by yeast) into liquid biofuels such as ethanol. Biomass converted to methane gas is called biogas.

Development

Wood biomass has been used for thousands of years to produce heat and energy. People have burned wood to warm their homes and cook their food. In the early twenty-first century, wood remains the most commonly used type of biomass. Many manufacturing plants use wood to produce electricity.

Wood-burning stove from the 1800s. Humans have burned wood biomass for thousands of years. *Robert J. Huffman/ Fieldmark Publications.*

During the Industrial Revolution in the 1800s, the world began to rely more on fossil fuels such as oil and coal. These fuels were not only inexpensive, but they were highly effective for providing power to industries—and later to cars and other types of vehicles. Fossil fuels continued to dominate energy usage through the twentieth

Efficient Land Use

Biomass is a cleaner source of energy than fossil fuels and it is renewable. But it is not without potential problems. When wood and crops are harvested to use for energy, there is the possibility that their use might lead to deforestation (the removal of trees that eventually destroys the forest) and deplete crops needed by people for food. To prevent these problems, the areas from which biomass is pulled need to be replanted and regrown.

century. In the 1970s, there was an oil crisis. Oil prices soared and fuel was in short supply. In response, governments and scientists began searching for other energy sources that were cheaper, cleaner, and renewable. Biomass was one of the main renewable energy sources developed and its use has increased gradually since the 1970s.

Wood can still be used as it was years ago, by burning it in stoves to heat homes, but this process is not efficient because it can only heat a very small space. A more efficient way to use wood and other types of biomass is to process them in a biomass power plant. These power plants are most commonly used in factories and other industrial areas.

One way to use solid biofuels is a direct-fired system. The biomass fuel is burned in a large furnace. Burning the fuel produces heat, which is used to produce high-pressure steam. The steam is directed into a machine called a turbine (a machine consisting of blades attached to a central shaft that is used to generate electricity). As the steam flows over the turbine blades, it causes these blades to rotate. The turbine is connected to an electric generator. When the turbine rotates, the generator turns, creating electricity.

Current Issues

The advantage to biofuels is that, because they are made from organic materials (material that comes from living organisms), they are easily renewable and their sources can grow back relatively quickly. Fossil fuels, such as oil, coal, and gas, are nonrenewable energy sources because they take millions of years to regenerate, and they may eventually become depleted. Using biomass for energy recycles wastes that might otherwise be dumped in landfills (large outdoor places where wastes are disposed).

Words to Know

Biogas: Biogas is methane produced by rotting excrement or other biological sources. It can be burned as a fuel.

Biomass: Any biological material used to produce energy.

Carbohydrates: Carbon-containing compounds that form the supporting tissues of plants. Found in abundance in foods made from grains.

Deforestation: Removal of trees from an area.

Fermentation: The process of breaking down sugar without oxygen into simpler substances, commonly alcohol and carbon dioxide.

Organic materials: Any biomass of plants or animals, living or dead. The most important form of organic matter in soil is dead or decaying.

Photosynthesis: Biological conversion of light energy into chemical energy by plants.

Turbine: A device consisting of a series of baffles mounted on a wheel around a central shaft used to convert the energy of a moving fluid into the energy of mechanical rotation.

When plants grow, they take in carbon dioxide and release oxygen. When they burn, carbon is released into the environment and combines with oxygen to produce carbon dioxide. Carbon dioxide and other greenhouse gases are thought to be involved in the process of global warming. Because plants absorb carbon dioxide when they grow and release it when they burn, they do not add carbon dioxide to the environment like fossil fuels. This means that biofuels are a cleaner alternative than fossil fuels.

Biomass does release some pollutants. Burning wood, for example, releases carbon monoxide and tiny particles, called particulate matter, that stay in the air for long periods of time. When companies burn wood to produce energy, they must use special filters to prevent harmful gases and particles from being released into the air.

As of 2006, only a very tiny percentage of energy in the United States came from biomass. One of the main reasons solid biofuels are not commonly used is that they are not as efficient as fossil fuels for powering generators, and therefore, not as economical.

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[*See Also* **Vol. 2, Biofuels, Liquid; Vol. 3, Ethanol.**]

Biological Crop Rotation

Description

When farmers grow two or more crops or sets of crops alternately on the same land, they are rotating crops. Plants are chosen based on their specific characteristics so that each crop cycle can complement the previous one.

Crop rotation helps reduce soil erosion. Soil erosion occurs when the top layer of the soil and its components wear away due to excessive human activity and poor land use. Some plant varieties used in crop rotation do not require the farmers to plow the land after the crop has been harvested. This saves the time and effort that goes in turning the soil over between successive crops.

Crop rotation offers a multitude of advantages, such as providing a natural solution to maintaining and enhancing soil fertility, enhancing pest and weed control, reducing the risk of weather damage, increasing yields, and promoting a green environment by avoiding the use of chemicals.

Scientific Foundations

The nutrient requirements of each plant species are distinctive. If the same plant is grown season after season, the soil eventually will be drained of the nutrients required by that plant. Crop rotation allows the soil to replenish nutrients absorbed by the first season crop, while the second season crop can grow on those nutrients that are unused by the previous season's crop.

Insects and other pests prefer certain plant species. In addition, plants of the same species or family often harbor the same set of disease-causing organisms. Pests also multiply rapidly, if there is a

Alfalfa plants (green) are alternated with corn to return nutrients to the soil on a farm in Iowa. © *Corbis.*

favorable environment. By alternating crops each year, the pest cycles can also be controlled.

Growing crops with varying root lengths also makes the best use of farmland. Both shallow-rooted and deep-rooted crops can absorb water and other nutrients from different sections of the soil without depleting the nutrient supply.

Development

Crop rotation is not new. Humans have practiced crop rotation since the very beginnings of plant domestication (farming). When soil fertility declined due to repeated growth of the same plant on the same piece of land, humans gradually realized the importance of rotating crops by observing and understanding life cycles of plants, the soil in which they grow, and other organisms associated with them. In short, the advantages of crop rotation are the reasons it has become one of the most important agricultural techniques.

For a long time, farmers followed a three-year crop rotation program in which the land was cultivated for two years and then

Turnip Townshend

Charles Townshend was the Secretary of State for King George I, in the late seventeenth century. He took to farming only after his retirement in 1730. Owing to the success of the four-year crop rotation system that he introduced, people gave him the nickname ''Turnip'' Townshend.

left uncultivated or fallow during the third year. The fallow year allows the soil to rest so that it can regain its nutrients and fertility.

In the eighteenth century, an English statesman and agricultural enthusiast named Charles Townshend (1674–1738) tried a four-year crop rotation system instead of the standard three-year cycle. Along with growing crops suitable for humans, he introduced cultivation of fodder crops, such as turnips and clovers, which were unheard of earlier. A fodder crop is fed to livestock.

Before the four-year crop rotation cycle was adopted, scarcity of fodder during the winter forced people to slaughter their animals before the cold season began. Growing a fodder crop made it possible for the farmers to have enough food for their animals even during the winter months.

The four-year crop rotation system presented several advantages. Since it made abundant food available for animals, farmers did not have to slaughter their livestock each autumn and the size of their herds could increase. Since clover (also called alfalfa) is more nutritious than grass, animals fed this fodder are healthier and of higher quality. When the farm animals grazed the crop in the field, their manure provided a natural fertilizer to enrich the soil.

Four-year crop rotation helped farmers do away with the need of “resting” a field by leaving it vacant. Instead, farmers could now “rest” the land by growing useful crops that replenished the soil with nutrients.

Current Issues

The principles of crop rotation require the planning and managing of multiple operations. Some farmers are quite apprehensive at the prospect of planning several things for a long term. In addition, if one of the crops grown as a part of a rotation has low market value, the farmers may become less enthusiastic about following the program.

Industrialization and mechanization pose a serious threat to soil quality. Some developing countries still follow out-dated and inadequate

Words to Know

Crop: An agricultural product that is grown and collected, usually on a farm.

Sustainable agriculture: Agriculture that meets the needs of the present generation, without compromising those of future ones.

waste management policies that result in the dumping of harmful chemicals in the water system. These chemicals eventually can seep into the soil rendering it barren within a few years. Sustainable agriculture, which refers to an innovative range of farming practices capable of providing environmental, social, economic, and political benefits, is one strategy to improve agricultural practices worldwide. It has crop rotation at its core. Using crop rotation techniques effectively makes the best use of the farmland available, which contributes to sustainability.

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[*See Also* **Vol. 2, Agriculture.**]

Biological Pest Control

Description

Insects and other pests are a big problem to farmers and other people in the farming industry because they can destroy crops. Traditional chemical pesticides can kill these pests, but they can also harm nearby animals, plants, and people, as well as the environment.

Biological pest control uses natural living organisms to kill pests before they can destroy crops. It may mean introducing a natural enemy such as a predator (an insect or animal that kills and eats other insects or animals) or a parasitoid (a kind of insect that lays its eggs in a host, then kills the host and uses it for food). Or, it can mean introducing a pathogen—an organism that causes disease in the pest—such as bacteria or a virus.

Scientific Foundations

In nature, there are insects that feed on crops. Humans consider these insects to be pests. There are also other insects and diseases that naturally kill those insect pests. Biological pest control uses these natural killers to target the pests that are damaging crops.

Predators, parasitoids, and pathogens are considered the natural enemies of crop pests. Predators are insects, such as ladybugs or spiders, which kill specific types of insects. These predators can be used to control insect populations.

Pathogens are bacteria, viruses, or fungi (plant-like organisms that cannot make their own food and must feed off other organisms) that cause disease in pests. For example, *Pandora neoaphidis* is a type of fungus that infects insects called aphids.

Ladybug and ant on apple leaf. The tiny insects around them are aphids. Both ladybugs and ants eat aphids, which helps farmers because aphids damage crops. *Nigel Cattlin/Photo Researchers, Inc.*

Parasitoids are insects that lay their eggs in other insects. They then kill their host and use its dead body as a cocoon (a case that protects the insect's young) or for food.

Development

Biological pest control began in ancient Egypt with the use of cats to control the rodent population. Many years later, the farmers in China used ants to stop insects from destroying citrus trees. They made bridges out of bamboo to help the ants move from tree to tree.

Scientists discovered insect parasites in the seventeenth century. An Italian scientist named Aldrovandi noticed the cocoon of one type of insect attached to the larvae (the wormlike stage of insect development that starts after the young hatches from the egg) of another type of insect. In 1700, the Dutch scientist Antoni van Leeuwenhoek (1632–1723) described insect parasitic behavior.

The first importation of a species for insect control occurred in 1762, when the mynah bird was brought to the island of Mauritius

The Unintended Side Effects of Introduced Predators

Sometimes introduced predators become a bigger problem than the pests they were introduced to control. For example, barn owls were introduced in Mauritius in the 1940s and 1950s to control rats. They certainly ate the rats, but also preyed upon native species of birds, such as fairy terns, and there is now a reward for killing barn owls. The small Indian mongoose was introduced to a number of Caribbean islands in the nineteenth century to kill the rats and snakes that infested sugarcane fields. Again, the mongooses did kill the rats and snakes, but their populations grew and they began to also kill a number on species of native birds, reptiles, and mammals. In Jamaica, the mongoose has been linked to the extinction of five native species—one lizard, one snake, two birds, and one rodent.

from India to help control locusts. Charles Valentine Riley (1843–95) is said to be the father of modern biological pest control. In 1873, he shipped an American predatory mite to France to protect against an insect that was destroying grapevines. His actions helped save the French wine industry.

Today, scientists use biopesticides and biological control methods to kill pests. There are several types of biopesticides. Microbial biopesticides contain a bacterium, virus, or fungus that is either in its natural state, or that has been altered by scientists in a lab. These microbes produce a toxin (a poisonous substance) that kills the pest, or they cause a disease in the pest.

Biochemical pesticides are natural substances that interfere with the pest's ability to live normally. For example, substances called pheromones are natural chemicals that insects use to find a mate. Artificial pheromones can interfere with the mating process and slow the pest's ability to reproduce.

Plant-incorporated protectants (PIPs) are pesticides produced by the plant itself. They are created by inserting a gene (a section of DNA that codes for a certain trait) into the plant. The gene causes the plant to produce substances that destroy the pest.

Biological pest control uses the pest's natural enemies to reduce its numbers. Scientists might travel to the country from which the pest originated, bring back its natural enemies, and introduce them into the area in which the pest now lives. Or, they may breed the pest's enemy in a lab to increase its numbers.

Words to Know

Bacteria: Microscopic organisms whose activities range from the development of disease to fermentation.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Microbe: A microorganism or germ.

Pesticide: A chemical meant to kill plants or insects that hurt crops.

Pheromone: Smell-producing chemical that provides communication between animals.

Predator: An insect or animal that kills and eats other insects or animals.

Toxin: A poison that is produced by a living organism.

Virus: A very simple microorganism, much smaller than bacteria, that enters and multiples within cells. Viruses often exchange or transfer their genetic material (DNA or RNA) to cells and can cause diseases such as chickenpox, hepatitis, measles, and mumps.

Current Issues

The advantage to biological pest control is that it does not use chemicals like other pest control methods, so it does not harm animals, plants, or humans. In addition, it is safer to the environment. Using biological pest control together with better plant growing strategies and a minimal use of chemical pesticides is called integrated pest management (IPM).

However, using biological pest control is not as easy as spraying a chemical pesticide on plants. It takes a lot of time and effort. Scientists may spend years identifying the enemies of a particular pest, and then developing an understanding of the biology of those enemies. And unlike regular pesticides, which kill a large number of different insects, biological pest control targets only specific types of insects. This means the process can take a long time and can be very expensive to use.

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[*See Also* **Vol. 2, Agriculture; Vol. 2, Biological Crop Rotation; Vol. 2, Bt Insect-Resistant Crops; Vol. 2, Bt Sprays; Vol. 2, Disease-Resistant Crops; Vol. 2, Hybrid Plants.**]

Biopreservation

Description

Biopreservation refers to the use of microorganisms—mainly bacteria (one-celled germs that can cause disease)—to curtail the growth of other, undesirable microorganisms that would otherwise contaminate or spoil a product. An example of biopreservation is the deliberate introduction of bacteria from a group called lactic acid bacteria into various foods products, including fish and vegetables. The growth of the lactic acid bacteria makes it more difficult for a disease-causing (pathogenic) bacterium called *Listeria monocytogenes* to grow.

Biopreservation can also refer to the deliberate use of environmental conditions that cause a target microorganism to stop growing and become metabolically inert (inactive). The still-living microbe then has a better chance of surviving inhospitable conditions that would kill their actively growing and dividing counterparts. This form of biopreservation can be useful in storing commercially and medically important microorganisms.

Scientific Foundations

The use of microorganisms as a means of minimizing the spoilage and contamination of foods has its origin in experiments conducted beginning in the 1980s that demonstrated the beneficial health effects of the deliberate introduction of bacteria in the body. This research showed that the introduction of bacteria called *Lactobacillus* could reduce the adherence of pathogenic (capable of causing disease) bacteria. Similarly, research has shown that a chemical ingredient in cranberry juice can block a site on the surface of intestinal cells that is used as an anchor for the binding of a pathogenic version of the bacteria *Escherichia coli*.

Two men in Germany making sauerkraut by spreading salt over cabbage in a barrel and letting it ferment with lactic acid bacteria, in 1954. © *Bettmann/Corbis.*

The use of bacteria and other microorganisms as medical and nutritional aids—an approach called probiotics—led to the use of bacteria as food biopreservatives. For example, growth of lactic acid bacteria in a food will lower its pH (a chemical measure of acidity or alkalinity) because of the production of the acid. The lower pH makes the food less hospitable for problematic bacteria, which slows their growth.

The benefits of food biopreservation can be profound. As an example, ingesting food contaminated with *Listeria monocytogenes* can cause a disease called listeriosis. The disease kills 20 to 40

Biopreservation in Cell Transplantation

The ability to routinely transplant cells and even whole organs from one person to another could be greatly aided by the ability to store the cells and organs for longer periods of time. Currently, the only way to store tissues is at very low temperature, which can destroy some of their components such as proteins. Scientists are exploring the use of biopreservation of proteins and even entire organs using microorganisms that are resistant to dessication (the removal of water). Transfer of a protein species to a dessication-resistant microbe could preserve the protein; subsequently the protein could be extracted from the microbe for use in a transplant. Although it is currently in the experimental stages, biopreservation of transplantable materials may some day be a routine feature of medicine.

percent of those who become infected. Pregnant women, infants, the elderly, and people whose immune systems are not operating efficiently are particularly at risk from listeriosis.

Development

Biopreservation of foods as varied as fish products and various types of fruits and vegetables is being explored for routine use.

In 2006 the United States Food and Drug Administration (FDA) approved the use of a spray containing six different bacteriophages (specialized viruses that specifically target bacteria) as a means of protecting the surface of meat and poultry from contamination with bacteria such as *Listeria.* The use of bacteriophages as a biopreservative had been investigated for at least a decade as a means of reducing diseases including fire blight in apples and bacterial spot of both tomato and peaches. As well, bacteriophage biopreservation has been shown to extend the shelf life of raw meat that is kept at refrigeration temperatures.

While FDA approval has been granted, limitations of the approach presently limit its usefulness. The fact that a given bacteriophage infects only one or a very limited number of types of bacteria is a disadvantage. Another, much more problematic disadvantage, is the potential that a bacteriophage can act as a vector to transfer genes from one bacterium to another. Thus, an undesirable trait could result by the use of a bacteriophage biopreservative.

Current Issues

While biopreservation of food is a very promising approach to maximizing food quality, more research is needed to ensure that the

Words to Know

Dessication: The process of removing water.

lactic acid and other types of bacteria selected as the biopreservative do not themselves cause as-yet unforeseen problems. The likelihood of this is fairly remote, since lactic acid bacteria have been studied for over a century.

Furthermore, the current limitations with the use of bacteriophages will need to be overcome if the approach is to become feasible for the safe, large-scale biopreservation of foods.

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Biotech in the Dairy Industry

Description

Biotechnology finds immense commercial application in the dairy industry as it can be used to enhance the economic and nutritional benefits of milk-producing animals. For instance, recent advances in biotechnology have helped develop genetically enhanced bovine growth hormone (BGH), a naturally occurring hormone in cows that controls their milk production. The genetically enhanced BGH increases milk production in cows without added costs of high-quality fodder (a crop, such as turnips or clover, that is fed to livestock).

Biotechnology has also made a significant impact on the dairy industry by improving the quality of animals. This is done using a technique known as embryo duplication and transfer. A cow embryo is a baby cow in its earliest stage of development inside the mother cow. Instead of allowing the most desired cattle and the less desired cattle to produce similar numbers of calves, the number of the most-desired cattle can be increased by duplicating (cloning) their embryos and implanting them in other, less-desired cows. Embryo duplication has several advantages. These include producing embryos (and subsequently calves) with desired qualities in a short time, allowing birth to an increased number of high quality offspring, preventing and controlling diseases in cattle, and developing purebred exotic breeds.

Scientific Foundations

Soon after sexually reproducing animals (those animals that need a male and female to create offspring) become pregnant, life is created in the form of a single cell known as zygote. The zygote then multiplies to form a mass of several cells called an embryo. Initially, all cells in an embryo are identical, and each embryonic

McIntosh Embryo Transfer

Embryo transfer specialist with four calves, produced by eggs from one cow and transferred to surrogate cows. © *Ted Spiegel/Corbis.*

cell is capable of growing into a complete individual. Even identical twins start as a single zygote, eventually splitting into two cells during the embryonic stage. Subsequently, they become two fully functional embryos.

In the dairy industry, to increase the number of superior calves (those that provide better quality milk and other dairy products), scientists use the embryo duplication and transfer technique to duplicate embryos of healthier parent cows. All embryos obtained in such manner are genetically identical to each other. Each of these embryos is then transferred to a suitable surrogate mother. Excess embryos can be retained for long periods by freezing them.

Development

In 1890, English biologist Walter Heap successfully transferred embryos from one female rabbit to another, proving that the biological mother need not give birth to its offspring. Later studies proved that the genetic makeup of the embryo is that of its biological parents. The surrogate only provides a suitable environment for the embryo to develop.

Duplication of a Multi-Cellular Organism

In 1952, researchers transplanted a nucleus from a frog's embryo into an unfertilized egg from which the nucleus had been removed. These injected eggs developed into tadpoles (very young frogs), which died before growing up into frogs. Although the tadpoles did not become adults, these experiments were the first time the nucleus of a cell was transferred to duplicate a multi-cellular organism.

At the time, embryo transfer was expensive and the success rate was low. Gradually, biologists and scientists realized that the success rate of embryonic transfer can be improved if healthy animals were used to transfer multiple embryos.

Biologists then discovered the process of embryo duplication. In 1901, German biologist and Nobel Prize winner Hans Spemann (1869–1941) succeeded in splitting a single embryo into two. Later in 1914, Spemann showed that the nucleus (part of the cell that contains genetic material) is essential for development of the embryo. In his experiments, the embryonic cells from which the nucleus had been removed stopped growing. The cells resumed development after the nucleus was reintroduced.

Many industries, including the dairy industry, started using embryo duplication and transfer to enhance the quality of their products. However, due to the fact that cattle typically produce one embryo at a time, these techniques remained largely limited until follicle-stimulating hormone (FSH) was discovered in the 1950s. FSH is a chemical that makes the donor produce several eggs, each of which is capable of being fertilized and producing an offspring. The discovery of FSH greatly improved the prospects of embryo transfer as production of multiple eggs increases the success rate of such techniques.

Further experiments laid the foundation for nuclear transfer technology. This technology involves transferring the nucleus from an adult cell to an unfertilized egg from which the nucleus has been removed. The egg fertilized with a nucleus from an adult cell is eventually transferred to a suitable surrogate. Nuclear transfer technology enabled the birth of Dolly the sheep—the first mammal to be cloned.

Current Issues

Embryo duplication and transfer is being used extensively in the dairy industry. Such advances in biotechnology have significantly improved the output of this industry. Known as bioengineered

Words to Know

Embryo: A stage in development after fertilization.	**Surrogate:** A female who carries another animal's genetic offspring.

foods, products from higher quality cattle that were born as a result of embryo duplication have ensured improvement in quality. The dairy industry is now producing far superior farm products in today's quality-conscious society.

Nations that are not developed and have restricted technology are also using duplication and transfer techniques to produce high-quality offspring from low-quality cattle.

Critics claim that embryo duplication and transfer and the associated technologies have converted the dairy industry into an assembly line manufacturing unit. Parent animals are selected for traits suitable to humans. Calves are conceived only if they have superior genes. After birth they are fed a diet specific to their intended purpose—use for production of meat, milk, or some other purpose. Every phase of their lives is programmed to serve humans, making dairy animals living robots.

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[*See Also* **Vol. 2, Animal Cloning.**]

Bovine Growth Hormone

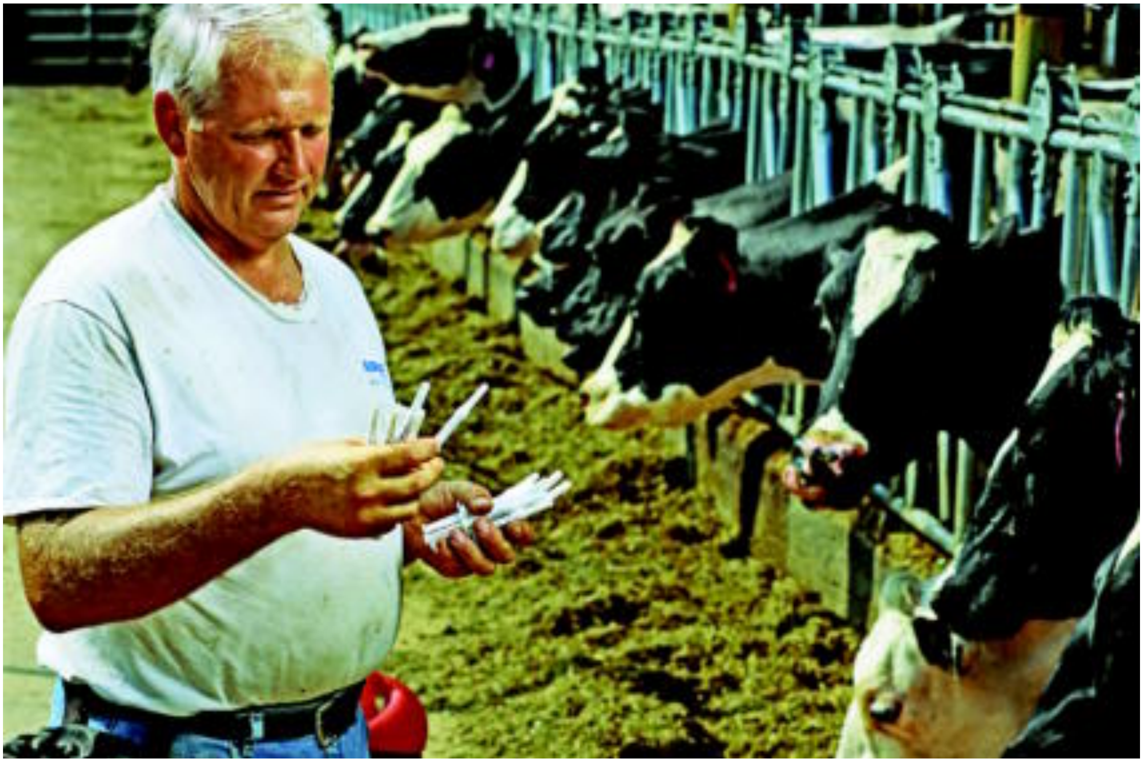
Description

Growth hormone is a substance that is made by glands in the brains of all mammals. It signals the body to grow during from infancy to adulthood. Different animals have slightly different growth hormones; bovine growth hormone is the growth hormone found in cattle (cows and bulls). When fed to cows that are giving milk, bovine growth hormone causes them to make more milk—about a tenth more than they would otherwise.

Scientific Foundations

In the 1980s, scientists inserted the gene for bovine growth hormone into a type of bacteria (a one-celled germ that can cause disease). This gene, a segment of genetic material that tells cells how to do a particular job, told bacteria how to make bovine growth hormone. Scientists could then grow these genetically modified bacteria and harvesting the hormone made by them. This hormone could then be sold to dairy farmers, who would give it to their cows in hopes of making more milk and therefore more money per cow. The bacteria used to make bovine growth hormone is *Escherichia coli*, the most common germ in the human gut (digestive system).

Bovine growth hormone made by genetically engineered ("recombinant") bacteria is called "recombinant bovine growth hormone," rbGH for short. (rbGH is also sometimes called recombinant bovine somatotropin or rBST.) rbGH is sold by the Monsanto corporation under the brand name Posilac®. It is injected into cows after they give birth, just before their milk production begins to decline, and keeps the cows making milk longer.



Wisconsin farmer alongside his cows, holding syringes of bovine growth hormone (rBST). © *Jim Richardson/ Corbis.*

As of 2006, rbGH was not approved for use in some countries because of concerns about animal and possibly human health. These included Japan, Australia, New Zealand, Canada, and all the countries of the European Union (twenty-five countries).

Development

Scientists first understood the nature of DNA (deoxyribonucleic acid), the molecule that governs heredity in all living things, in the early 1950s. By the end of the 1970s, they had invented ways of taking pieces of DNA (genes) from some living things and adding them into the DNA of others. This practice is called genetic engineering. Some of the first profitable uses of genetic engineering were using bacteria to make rbGH and insulin for human beings with diabetes.

Testing of rbGH in cows began in 1982. After ten years of study, the U.S. Food and Drug Administration (FDA), which decides what products can legally be sold as food or medicine or used in making food in the United States, decided that milk and meat from cows given rbGH were the same as those from other cows and

Make That a Double

In 2006, Dr. Gary Steinman published a study in the *Journal of Reproductive Medicine* that was widely reported in the scientific press: women who drink milk are more likely to bear twins than women who do not. Also, Steinman said, women who drink milk from cows treated with rbGH are more likely to bear twins than women who drink milk from untreated cows. The reason appears to be the substance IGF-1 (insulin-like growth factor), which is found in all cow milk and which encourages cells to divide. Milk from cows treated with recombinant bovine growth hormone (rbGH) has about three times as much IGF-1 in it as milk from untreated cows. The magazine *Scientific American* said that Steinman's research ''seems to show that bovine growth hormone in the food supply may be responsible'' for the fact that the rate of twin births in the United States has almost tripled in the last thirty years. This claim is startling because the U.S. government and Monsanto, the maker of rbGH, have been saying since the 1980s that giving rbGH to cows cannot possibly have any effect on the humans who drink the milk. Steinman's scientific work is certain to be closely checked for accuracy in the years to come.

could be eaten safely by humans. Commercial use of rbGH was approved by the FDA in November 1993.

All rbGH sold today is made by the Monsanto corporation. In the United States, about a third of all dairy cattle were being injected with rbGH as of 2006.

Current Issues

There are several issues or disputes about rbGH:

Economics. Farmers buy rbGH because they hope they will earn more money by selling the extra milk that rbGH causes their cows to make. However, there is disagreement among experts about whether farmers who use rbGH really do make any more money. A 2004 study in the journal *Review of Agricultural Economics* found that, on average, using rbGH made no difference in the amount of money earned per cow "even if Monsanto provided [it] free to the using farmers."

Animal health. The label on the rbGH containers sold to farmers warns that cows treated with rbGH have higher rates of several problems, including udder infections, foot problems, disorders of the uterus, diarrhea, and twin births.

The suit against Oakhurst. In 2003, Monsanto sued the Oakhurst Dairy company of Portland, Maine, because Oakhurst printed on its milk boxes the words, "Our Farmers' Pledge: No Artificial

Words to Know

Recombinant bovine growth hormone: Bovine growth hormone made using genetically engineered (recombinant) bacteria. Called rbGH for short. Given to cows to increase milk production.

Insulin-like growth factor: A substance called IGF-1 for short, that is found in milk. More IGF-1 is found in milk from cows treated with recombinant bovine growth hormone and may increase the rate of twin births in women who drink such milk.

Growth Hormones." Monsanto complained that since they were the only sellers of artificial growth hormone for dairy cow, the label must refer to them, and that that the label was lying because it was designed to make milk buyers think—incorrectly, Monsanto said—that there was a difference between milk from cows getting rbGH and other cows. The suit was settled when Oakhurst agreed to add the words, "FDA states: No significant difference in milk from cows treated with artificial growth hormone."

Human health. There is about three times as much of the substance called IGF-1 (insulin-like growth factor) in milk from rbGH-treated cows as in milk from untreated cows. Several scientific studies have found that in human beings, high levels of IGF-1 in the blood tend to be associated with certain kinds of cancer (prostate cancer and breast cancer). However, as of mid-2006, no studies had shown that milk from cows treated with rbGH made human beings more likely to get cancer.

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[*See Also* **Vol. 2, Agriculture; Vol. 3, Animal Research and Testing; Vol. 2, Biotech in the Dairy Industry.**]

Bread-Making

Description

Throughout history, humans have been consuming bread in some form. Its importance can be determined from the fact that ancient Egyptian employers used bread as a mode of payment to daily workers. However, breads of ancient times were entirely different from the soft white bread now widely available.

Most global cuisines offer several types of bread prepared in ways similar to each other. All breads are typically made of flour obtained from grinding grains through a process known as milling. Different types of flour can be produced using different proportions of grains. These flours can be used to bake various types of bread.

Scientific Foundations

Bread is essentially a baked mixture of flour and water. Additives such as yeast, sugar, egg, milk, and fats help enhance its flavor, appearance, and digestive quality. Yeast makes bread soft by releasing gas bubbles in the dough. A key element in the bread-making process, yeast is a living, single-celled type of fungus that feeds on sugar and grows only under favorable conditions.

A process known as fermentation is used in the preparation of bread. During fermentation, yeast breaks down sugar (that is added to flour) into carbon dioxide and alcohol. Carbon dioxide, the gas that soda bubbly, makes the dough fluffy, while alcohol flavors the bread.

Gluten, a natural chemical present in flours, makes the dough elastic. It also ensures removal of the carbon dioxide released during fermentation. Subsequently, the amount of gluten used for making bread determines its final volume. Kneading (pressing and working a

Woman in Greece baking bread in a stove oven. © *Franz-Marc Frei/Corbis.*

mass of dough with the hands) makes the gluten work better in forming a bigger framework to trap the released carbon dioxide.

Development

Studies indicate that bread probably did not exist until 4500 BCE, although farmers were growing grains by 8000 BCE. Farmers experi-

Ancient Grain-Milling Machine

Around 500 BCE, the Romans produced flour with a simple milling machine. This machine had as its base a stationary circular stone. On the top of this base, was another circular stone with a hole in the center and a handle on one side. The miller filled the opening in the top wheel with grain and used the handle to turn the wheel. The grain was crushed between the two stones, and flour came out from the tiny gap between the wheels. Milling machines of this simple design are still used in rural areas of some developing countries.

mented with boiling and crushing the grain. Thick pastes of crushed grain and water were rolled into flat breads that were left to dry naturally or baked in a fire. Tortillas originated in this manner.

Leavened (raised) bread was probably discovered by accident, and the process by which it was made was improvised for a long time before it acquired its present form. Loaves of bread have been found in the Egyptian pyramids, a fact that demonstrates the importance of bread to the early Egyptians. Studies show that the Greeks learned the taste and technique of making bread from the Egyptians, who used beer foam to make the bread dough rise. Subsequently, centuries ago, the Europeans acquired these skills from the Greeks.

The Europeans during medieval times used a bit of sour dough as a starter from previously baked bread. Sourdough bread is still prepared in this manner. Around the same time, people also experimented with using different grains, flours, nuts, liquids, and leavening agents for enhancing the bread-making process.

Eventually, refined and coarse flour were used to makes breads. The bread made of refined flour was lighter, smoother, whiter, and preferred by the rich. Poor people, who could not afford the more expensive refined white bread, had to be satisfied with brown bread. As white bread generated more money, bakers started using chemicals, such as alums and lime, to produce even whiter bread. Bread color conveniently showed the financial and social status of the consumer. By the year 1700, white bread was at the peak of its popularity. Even today, it is an important part of breakfast for millions of people all over the world.

With time, grain-crushing technology has also evolved, giving rise to the present milling process. Grain-milling machines are now used to produce flours of varying textures, protein content, flavors, and

Words to Know

Fermentation: The process of breaking down sugar without oxygen into simpler substances, commonly alcohol and carbon dioxide.

Gluten: A mass of waste protein obtained from wheat or corn that is used as a raw material for producing MSG.

Leaven: Yeast, baking soda, or baking powder that causes bread to raise by producing carbon dioxide gas.

Milling: Chewing and pulverizing hard seed into a powdery texture.

Yeast: A microorganism of the fungus family that promotes alcoholic fermentation, and is also used as a leavening (an agent that makes dough rise) in baking.

aromas. Commercial bread-baking uses a mixture of several flours. Scientists have also developed yeast varieties that cut down the time required for the fermentation process so that the dough can rise quickly.

Current Issues

Bread-making is now an industry of its own. We clearly understand how to make leavened breads using yeast, and numerous recipes for many different varieties of bread can be found in cookbooks and on the Internet. Scientists are experimenting with growing genetically enhanced varieties of wheat and other grains. Research also is underway to develop gluten-rich, high-nutrient, and disease-resistant varieties of grains.

However, there are several quality issues associated with the bread-making process. Although the flour used in bread-making is said to be refined, it yields bread that only looks refined. The refining process results in loss of several nutrients from the flour. In addition, chemicals, such as dough softeners, flavoring agents, bleaching agents, and preservatives are added to increase the shelf life of the bread and to enhance its appearance and taste. Consequently, many commercial breads are not very nutritious.

As a result, many bakeries have switched to making bread using classic recipes and traditionally milled flours. Quality is taking precedence over appearance. American grocery stores now carry a variety of healthy breads ranging from simple whole wheat bread to multigrain bread, oat bread, and sourdough bread. In addition, many people have discovered the satisfaction of baking bread at home. Home-baked breads are often crustier, aromatic, and more flavorful, and the home baker can control the ingredients and exclude additives, such as preservatives. Some home bakers use bread-making machines, which knead the dough as well as bake the bread.

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[*See Also* **Vol. 2, Beer-Making; Vol. 2, Wine-Making.**]

Breeding, Selective

Description

Selective breeding is the selection by human beings of which plants or animals will breed with which others. The purpose is to make certain traits or characteristics in the present generation come out more strongly in future generations. For example, to breed larger ears of corn, one might raise next year's crop from kernels that grew on the largest ears of this year's crop. Over time, one's corn would tend to grow bigger and bigger ears, up to some natural limit. It was in just this way that South American Indians developed corn from the wild plant, teosinte (pronounced tay-oh-SIN-tay), starting about four thousand years ago.

Selective breeding is also called artificial selection. This phrase is used because the way evolution makes new breeds without human help is called natural selection. The only difference between the two kinds of selection is that in natural selection, the individuals that get to have offspring are chosen by survival, while in artificial selection, they are chosen by humans. Charles Darwin (1809–1882), who introduced the world to natural selection in his book *The Origin of Species* (1859), studied artificial selection to understand natural selection. He wrote, "It is wonderful what the principle of selection by man, that is the picking out of individuals with any desired quality, and breeding from them, and again picking out, can do. Even breeders have been astounded at their own results. . . . Man, by his power of accumulating variations, adapts living beings to his want—may be said to make the wool of one sheep good for carpets, of another for cloth. . ." (1858).

Selective breeding is often used by scientists studying natural selection and how genes affect behavior. For example, in one study, scientists used selective breeding to create a breed of fruitflies that fought with each other, and then looked for the genetic differences that caused the aggressive behavior.

Scientific Foundations

Many traits of living things are partly set by the DNA (deoxyribonucleic acid) molecules that pass on genetic information from one generation to the next. Most DNA is divided up into short lengths or units called genes. The genetic code or recipe for a plant or animal is built of genes much as a sentence is built of words. But most individuals even of the same species, such as cats, people, or wheat, do not have exactly the same genes. When some individuals reproduce more than others, the genes carried by those individuals tend to become more common in the group. This is how selective breeding and natural selection change the character of a group over generations.

Development

Selective breeding has been practiced by human beings for tens of thousands of years. All domestic animals and plants—cattle, sheep, dogs, chickens, cats, grapes, rice, and hundreds more—began as wild varieties and have been greatly changed by selective breeding.

Marker-Assisted Breeding

In the early 2000s, the power of modern biotechnology was added to the power of traditional breeding in the method called marker-assisted selection (MAS for short). In MAS, scientists decode the DNA of a plant that they want to breed to see which genes give it good qualities. These genes are considered ''markers'' of the good qualities. Then, they cross-breed the plant with others and produce many seeds, each with a different combination of genes. They then plant the seeds. Instead of having to wait months or years to find out which individuals have the best genes (as they must as when breeding apple trees, for example), scientists examine the young sprouts for the marker genes. The ones with the markers are the ones to keep. This method can greatly speed up the selective-breeding process. Critics, however, argue that it is a mistake to replace many varieties of crop plant with just a few that are supposed to be ''best.'' They argue that a wise system of agriculture would resist pests and conserve soil by growing many varieties together on smaller farms, rather than raising gigantic fields of genetically uniform crops, no matter whether they are produced by breeding or genetic engineering.

It was not until Darwin's explanation of evolution was combined with the understanding of genes, which were first described by Gregor Mendel (1822–1824) in the late nineteenth century, that humans were able to selectively breed plants and animals in a scientific way. The first wide application of artificial insemination to selective livestock breeding was in the 1930s. Artificial insemination is when sperm from a male animal is inserted artificially into a female. It is easier to send sperm across the country to a breeding farm than to transport the whole male animal, so artificial insemination became affordable to breed more selectively than before.

Today, breeders continue to work to make animals more useful to human beings.

Current Issues

Since the 1970s, genetic engineering has been used to add genes to many varieties of plants and a few animals. For example, most of the corn and soybeans grown in the United States today has been genetically engineered. However, genetic engineering has not replaced selective breeding. Many of the qualities that are needed in plants and animals are governed by large groups of genes, which tend to be passed on together when animals breed; genetic engineering, on the other hand, can only add three or four genes at a time, and there is

Words to Know

Artificial insemination: The process of placing male sperm into the reproductive tract of the female to increase the chances of fertilization. AI is one of the treatments for infertility among humans. With animals, AI is used as a means of producing superior offspring by selecting healthy parents with desired traits.

Artificial selection: Selective breeding, carried out by humans, to produce desired traits in domestic animals and plants.

little control over where these genes are inserted in the DNA. In fact, genetic engineering is a crude way to produce better crops and livestock compared to selective breeding, although certain DNA changes can be made that would never be possible with selective breeding.

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[*See Also* **Vol. 2, Agriculture; Vol. 2, Animal Cloning; Vol. 2, Genetic Engineering; Vol. 2, Hybrid Plants.**]

Bt Insect-Resistant Crops

Description

Bacillus thuringiensis (Bt) is a type of bacterium (a single-celled living thing) that has been used to control plant insect pests since the 1970s. It produces a chemical that paralyzes an insect's intestines, and the insect usually starves to death in several days. Thus, the chemical functions as a toxin (poison) to the insect. Bt is usually sprayed on the plant's leaves or needles and is ingested by the insect when it eats the plant.

Cells use DNA (genetic information) to control their functions. Genes are pieces of DNA that tell cells how to do a particular job. The gene that tells a cell how to make the Bt toxin can also be removed from *B. thuringiensis* and inserted into the genetic material of a target plant. The toxin can then be directly produced by this transgenic plant that now contains the Bt gene. Plants that produce the Bt chemical (or that have been sprayed with the Bt bacteria) become resistant to the destructive feeding of insects.

Scientific Foundations

Bt is naturally present in the soil. The ability of the bacterium to kill insects has been known since 1911, although the active compound was not discovered for decades. By 1961, Bt was approved as a biopesticide (biological insect-killer) in the United States.

The application of Bt to plants as a spray has several drawbacks. Because the bacterium must be eaten by the insect for the toxin to exert its deadly effect, environmental factors that reduce the concentration of the bacteria on the plant are a problem. For example, sunlight can lessen the strength of the bacteria and its genetic material, and rain can wash the Bt off of the plant.

A pigeon pea plant with the Bt gene for insect resistance. © *Pallava Bagla/ Corbis.*

These problems have been overcome using genetic engineering—the process whereby selected deoxyribonucleic acid (DNA) of one organism is removed from that organism and inserted into the genetic material of another organism, in this case the species of plant that would have been applied with Bt spray. As the plant manufactures more DNA as part of the cell division process, the inserted Bt gene is copied and the insect-killing chemical is produced. Thus, the plants themselves produce the Bt toxin.

When the plant's leaves are eaten by an insect pest, the toxin is ingested. In the insect's gut, the three-dimensional structure of the Bt protein is altered. The newly shaped toxin is now biologically active, and it destroys the intestinal tract of the insect. This chemical only has this effect on insects. Eating the toxin does not harm humans or animals.

Development

The process of genetic engineering—removing a piece of DNA from one organism and inserting it into a new organism—was discovered in the 1970s. To adapt this process for the creation of Bt

Bt Transgenic Plants Are Big Business

Since their commercialization in 1996, the popularity of Bt transgenic corn and cotton plants has exploded. In 2004, for example, these plants were grown on approximately 32 million acres in the United States, representing about 30 percent of the total acreage devoted to these plants. In that year, more than 55 million acres worldwide were planted in Bt transgenic corn and cotton.

transgenic (genetically engineered) plants, scientists first identified the gene in Bt that codes for the toxic chemical. Once the gene is known, the techniques of genetic engineering can be used. The gene is removed from the Bt genome using specialized chemicals. It is then combined with another gene that codes for a chemical that degrades a particular antibiotic. This gene combination is then inserted into plant cells, where it is taken into the plant's DNA. As the plant grows, its new cells express the chemical as directed by the transplanted gene combination. When grown in the presence of the antibiotic, the plant cells that are resistant because they produce the Bt/antibiotic-resistance protein can be identified. (Not all the plants take in the transplanted DNA effectively.) These cells are selected and grown into the Bt-expressing (producing) plants.

As of 2006, this technology has been used to create Bt-transgenic corn (which is resistant to the corn borer), potatoes (resistant to the potato beetle), and cotton (resistant to the tobacco budworm and varieties of bollworm).

Current Issues

One concern associated with Bt insect-resistant crops is the development of Bt resistance by the target insect species. Resistance is a natural process that aids an organism in surviving the challenge imposed by a lethal compound. Resistance happens when the organism's DNA evolves in a way that makes it better able to survive whatever caused earlier generations to die. In the case of Bt, resistance is a valid concern, since insects have developed resistance to conventional insecticides in the past. Moreover, the ability of insects to develop Bt resistance has been demonstrated in laboratory studies.

However, as of 2003, such resistance had not developed in nature to any significant extent. In 2005, researchers demonstrated

Words to Know

***Bacillus thuringiensis*:** A bacteria that produces a toxic poison to certain types of insects.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Resistance: An immunity developed within a species (especially bacteria) via evolution to an antiobiotic or other drug.

Toxin: A poison that is produced by a living organism.

Transgenic plant: A plant that has successfully incorporated a transferred gene or constructed piece of DNA into its nuclear or plastid genomes.

that plants engineered to express two slightly different versions of the Bt toxin are even more resistant to insects than plants expressing a single type of Bt toxin.

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[*See Also* **Vol. 2, Biological Pest Control; Vol. 2, Bt Sprays; Vol. 2, Corn, Genetically Engineered; Vol. 2, Cotton, Genetically Engineered; Vol. 2, Disease-Resistant Crops.**]

Cell structures inside these *Bacillus thuringiensis* bacteria are harvested and used as an insecticide in Bt sprays. © *George Chapman/Visuals Unlimited.*

Bt Sprays

Description

Bt spray refers to a spray form of a bacterium (a single-celled organism) called *Bacillus thuringiensis* (Bt) that is used to kill insects on plants (an insecticide). DiPel® is one Bt spray; it consists of a particular subtype (or strain) of Bt designated *Bacillus thuringiensis kurstaki*. Since this formulation is active against the gypsy moth, it is of particular interest in the control of tree damage caused by this moth species, which eats tree leaves. Other Bt sprays that consist of other strains of *Bacillus thuringiensis* are not active against gypsy moth, but are effective against other insect pests on farms.

Bt formulations such as DiPel are sprayed on the leaves of commercially important plants. For small areas, the Bt spray is applied by hand using a hand-held spray container. Spraying of entire fields is typically done using a crop-dusting plane.

DiPel is intended to protect plants from being eaten by lepidopterous insects (insects in the family that includes butterflies and moths), including the larval (caterpillar) form of the cabbage looper, cabbageworm, grape leaf folder, hornworm, cutworm, sod webworm, gypsy moth, and the tobacco budworm.

Scientific Foundations

The basis of Bt plant protectants, such as DiPel, is a protein (a substance in cells that performs cell functions) that is produced by the bacterium. When sprayed onto a plant, Bt can stick to the leaves. If the sprayed leaves are eaten soon after application of Bt, the microorganisms enter the insect's intestinal tract, where the toxic protein does its work. However, over time, the Bt on the leaves' surface may be broken down by the ultraviolet rays in sunlight or be washed off by rain.

In the insect gut, enzymes (biological chemicals that speed reactions) begin to degrade the Bt protein. The loss or alteration of some of the protein causes the three-dimensional structure of the Bt protein to change. In its new configuration, the protein disrupts the surface of the cells that line the insect's intestine. This disruption, which affects the ability of the insect to digest food, causes its starvation and death within a few days. Bt sprays, such as DiPel, are usually lethal only to the target insects.

Development

Bacillus thuringiensis (Bt) occurs naturally in soils worldwide. It was first identified by the Japanese biologist Shigetane Ishiwatari, who was studying a disease that was killing large populations of silkworms in Japan. In 1901, Ishiwatari isolated the Bt bacterium as the cause of the disease. In this case the death of silkworms was undesirable, because they are valuable in the making of silk), However, the death of insect pests who eat crop plants is desirable, because it gets rid of the pest problem. European farmers recognized this and began using Bt as a pesticide in the 1920s, and it became approved for use for the control of caterpillar crop pests in the United States in 1961.

With advances in biochemistry in the 1990s, scientists produced many different strains of Bt, inserted with genes encoded to produce specific toxins targeted for specific pests. (Genes are units of genetic material that contain recipes, or codes, for cells to produce proteins.) This allowed Bt to be used for specific insect problems, and reduced the chance that the spray would accidently harm another form of life.

The Scourge of the Gypsy Moth

Until the mid-nineteenth century, the gypsy moth was unknown in North America. In 1869, the moth was imported to the continent in an effort to improve the production of silk. However, the moth escaped into the wild. As the gypsy moth spread along the eastern coast of the United States and into Canada, the the moth's caterpillar fed on massive quantities of leaves, causing extensive defoliation of trees. In many urban areas, the landscape was drastically altered as entire trees were stripped of their leaves. Without the leaves to convert sunlight into useable energy, the trees died. While the gypsy moth remains a concern, the use of Bt has allowed municipalities to gain some control over defoliation.

The value of Bt spray was exemplified in Canada during the 1990s. Regions of Canada are forested, which has provided a financially valuable forestry industry. But, during 1994, over 15 million acres (6 million hectares) of forest was attacked and defoliated by the spruce budworm. The loss of leaves from the trees removed their source of energy in the form of photosynthesis, which led to massive tree death.

In response, a Bt spraying program was started. In some trouble spots, the program continues. The use of Bt spray controlled the spruce budworm problem.

In 1996–97, Bt spray was also used successfully used to kill an invading species of moth in Auckland, New Zealand. A health study done during the spray campaign did not find any evidence that the spray caused health problems for the residents of the city.

These and other incidents spurred the development of genetically modified trees that could express the Bt toxic protein. The gene that encodes for the production of the toxin was successfully inserted onto the DNA of some commercially important tree species and other plants. (DNA, or deoxyribonucleic acid, is the molecule of genetic information contained in nearly every cell.) As the plants grow, the DNA molecule is duplicated, to provide the new plants cells with a full complement of genetic material. Any gene that has been inserted into the DNA will be duplicated along with the hosts' DNA, and the protein that is coded for by the gene will be made. In 1995, the first genetically engineered plant, a type of corn resistant to certain pests, was registered for sale and use in the United States.

In 2006, over 1.1 million pounds (500,000 kilograms) of Bt spray were used in the United States, and the area used to plant Bt crops continues to grow.

Words to Know

***Bacillus thuringiensis*:** A bacteria that produces a toxic poison to certain types of insects.

Defoliation: Removal of leaves from a tree.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Insecticide: A chemical that kills insects. Used in agriculture to kill insects that eat crops.

Protein: Complex molecules that cells use to form most of the structures and control chemical reactions within a cell.

Current Issues

One concern associated with the use of Bt sprays is the possibility that their overuse could stimulate the development of resistance by the target species of insects. However, even after more than thirty years of agricultural and homeowner use, resistance has not developed to any appreciable extent in the field, although scientists have bred insects resistant to DiPel in the laboratory.

Other scientists have expressed concern that Bt sprays may be more toxic to untargeted species than is assumed. Citing several instances of reduced populations of butterflies in areas where Bt sprays were used to control moths, they argue that Bt sprays should be used only when necessary, and in the smallest quantities possible.

Another concern is the possibility that the Bt toxin gene could be transferred from genetically engineered plants to other species. If the recipient plant was an unwanted variety, the result could be a very environmentally hardy "superweed," some critics argue. Again, however, careful monitoring of engineered plants over decades has not revealed this gene transfer to be a problem. But, the possibility cannot be ruled out, and so approval of genetically engineered Bt-plants is done only after careful thought.

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[*See Also* **Vol. 2, Biological Pest Control; Vol. 2, Bt Insect-Resistant Crops; Vol. 2, Transgenic Plants.**]

Cheese-Making

Description

One of the most widely available foods in the world, cheese varies in texture, flavor, aroma, and shelf life (amount of time it can be eaten before spoiling). Some cheeses like Cheddar and Gouda are firm, whereas others such as Camembert and Brie are very soft. Cheeses that become stringy when heated are used in pizza. Moreover, cheeses like ricotta and mozzarella are used fresh, while Munster, Gorgonzola, and Roquefort are aged for a specific time.

Cheese is a dairy product made by curdling (condensing) milk and discarding the whey (the watery part of milk that remains after the solids are removed). Fresh cheeses are consumed soon after removing the whey. Other cheeses are stored for some time to develop distinct flavors—a process known as aging. Depending on the desired texture and flavor, a cheese may be left to age for as little as two weeks to as long as two years.

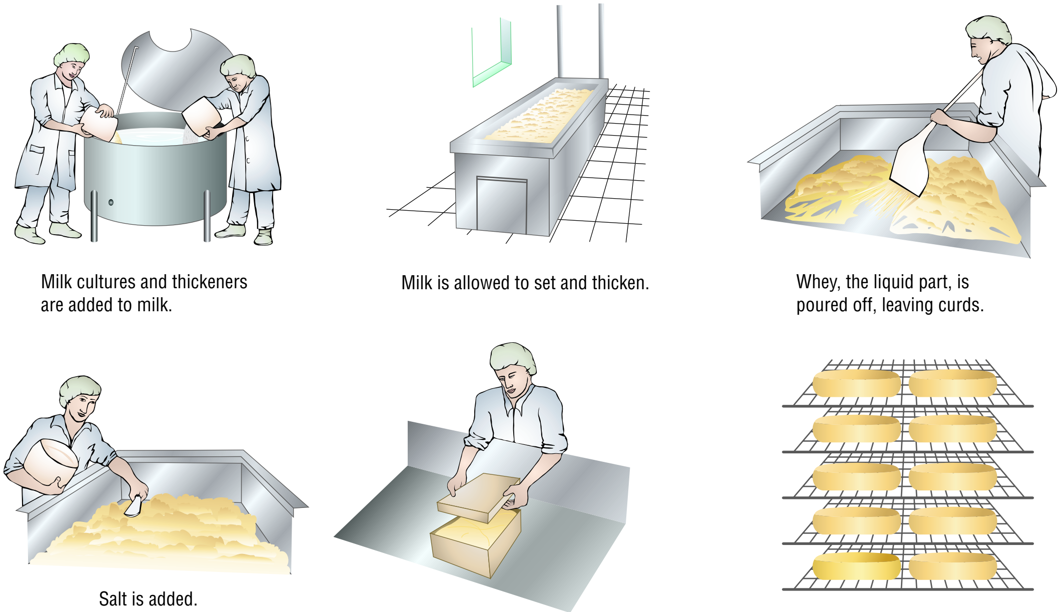
Small portions of cheese are a good source of calcium, phosphorus, protein, and fat. Also, making cheese is a good way of using excess milk, which becomes sour very quickly.

Scientific Foundations

The key steps involved in cheese-making are milk curdling, pressing the curd, salting, and aging. The amount of whey discarded at the time of pressing determines cheese firmness. Firmer cheese is produced by squeezing more whey out of the curds.

Microorganisms (living organisms so small that they can only be seen with a microscope), such as lactic acid bacteria (LAB), enhance the cheese-making process. LAB produce lactic acid, a chemical that helps in curdling the milk. LAB also help in restricting the growth of

Cheese making



Milk cultures and thickeners are added to milk.

Milk is allowed to set and thicken.

Whey, the liquid part, is poured off, leaving curds.

Salt is added.

Cheese is molded and pressed to remove remaining liquid.

Molded cheese is allowed to set and "cure."

How cheese is made from milk, salt, and agents like bacteria and enzymes that curdle (thicken) the milk. *Illustration by GGS Inc.*

harmful bacteria and in developing cheese texture and flavor. Salt is also added while making cheese. This helps to remove excess moisture, increasing the shelf life of cheese and enhancing its flavor. Finally, some cheeses, as mentioned earlier, are aged. Aging intensifies cheese flavor and texture.

Altering the process even minutely changes the taste and texture of the cheese. Factors that affect the final product are the breed and type of animal used as the milk source, the kind of food that the animal ate, the amount of milk fat, the kind of curdling agent used, the types of bacteria and molds introduced, the duration of aging, and the flavorings added.

Development

People have been making cheese for centuries. Cheese-making began as a way to preserve milk for longer periods of time. Later, it was discovered that something in the lining of an animal's stomach makes the milk curdle better. In recent times, rennet—an enzyme (biological catalyst) found in a calf's stomach lining—is used for curdling milk. Rennet is commercially produced and is one of the key ingredients used by the cheese-making industry.

Assortment of cheeses at a French restaurant. © *Corbis.*

It is thought that cheese was first produced by nomadic tribes in the Middle East. The oldest proof of cheese-making and the consumption of cheese comes from Egyptian paintings from 2300 BCE that show the steps involved in cheese-making.

Cheese was a very popular food during Roman times, and the process of cheese-making was very similar to the process used today. The Romans spread the art of cheese-making throughout their empire. It was introduced in Europe, where the cool climate enhanced the quality of cheese. Many European countries, such as France, Italy, and Switzerland, became known for the quality and varieties of cheese that they produced.

In 1815, the first cheese factory was established in Switzerland. Then, in 1851, Jesse Williams established the first American cheese factory in Oneida County, New York. This was the first time that industrial cheese production was successful. However, it was only in the following decades, when commercial rennet and other microbes were developed, that industrial production of cheese prospered.

What Causes Holes in Swiss Cheese?

Three kinds of bacteria are used in the production of Swiss cheese. One of these, *Propionibacter shermani*, is introduced late in the cheese-making process. It consumes the lactic acid excreted by other bacteria and releases carbon dioxide gas. This gas slowly forms bubbles and gives the cheese its characteristic holes (known as eyes).

Although the basic process for making cheese remains the same, advancements in biotechnology have enabled dairy farmers to improve the quality of cattle. These cattle give nutritious milk with more milk proteins, and these proteins enhance the texture and flavor of the cheese. With superior cattle, the quality of rennet and other enzymes has also improved.

The bacteria used in curdling milk are susceptible to viral infections. Because of this scientists use genetic engineering to develop virus-resistant bacteria, further aiding the cheese-making process. In the last few years, another commercially produced enzyme known as chymosin has replaced the use of rennet in some cheese-making operations. Obtained from genetically modified microorganisms, chymosin has a predictable action and few impurities. In 1988, chymosin was the first enzyme from a genetically modified source to be approved for use in food.

Current Issues

Cheese is an extremely popular food worldwide. A United Nations study indicated that the global production of cheese in 2004 was more than eighteen million tons—more than the combined annual production of tea, cocoa, coffee, and tobacco.

Since it is a milk product, cheese is a nutritious source of dietary calcium, minerals, and protein. However, unless it is made from low-fat milk, the fat content of cheese is very high. In the United States, fatty cheeses are seen as contributing to the obesity epidemic.

Cheese made from raw milk can sometimes cause infections and diseases, such as tuberculosis. To reduce this danger, the U.S. government requires all cheeses to be aged for a minimum of sixty days to ensure that no unwanted bacteria are present in the product.

Words to Know

Curdle:	To coagulate milk (create curds) with acidic substances.
Curds:	The lumps obtained by the mixing and coagulating milk with acidic substances and then draining off the liquid (whey).
Rennet:	An enzyme extracted from animal stomachs, used to curdle milk while making cheese.
Whey:	The liquid part of milk that is separated from the curd when making cheese and other products that curdle milk.

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[*See Also* **Vol. 2, Beer-Making; Vol. 2, Bread-Making.**]

Compost/Organic Fertilizers

Description

Some soils do not have enough, or the right amount, of nutrients to grow plants in the best way possible. To keep soil quality high, farmers and gardeners often add fertilizers to the soil. Fertilizers are inorganic or organic materials that increase soil's ability to grow strong and healthy plants. Inorganic (synthetic) fertilizers are fertilizers manufactured by chemical companies. They contain salts or minerals in concentrated form. Inorganic fertilizers are composed mostly of nitrogen, phosphorus, and potassium. Plants quickly absorb these fertilizers. Soil organisms such as bacteria and worms may be killed by these fertilizers.

Organic (natural) fertilizers are any type of natural materials, called soil organic matter, that come from plants and animals (such as compost, peat, manure, fish meal, seaweed, and ground bone) or minerals occurring in nature (such as limestone and sulfate of potash). Soil organisms such as worms and bacteria are used to turn them into organic fertilizers.

Compost, a type of organic fertilizer, is a nutrient-rich mixture of decaying or decayed plants and other organic matter (such as leaves and other plant parts) that is full of helpful soil microorganisms (living things are too small to be seen without a microscope, like bacteria). It is absorbed slowly into plants and does not kill soil organisms. Many gardeners and professional landscapers use organic fertilizers in their soils. Farmers who use organic fertilizers usually use other natural techniques in growing plants. They are called organic farmers.

Scientific Foundations

Soil organic matter is any dead piece of a plant or animal that is part of the soil. It is a mixture made of materials in various stages

Worms in a decaying compost heap. *Robert J. Huffman/Fieldmark Publications.*

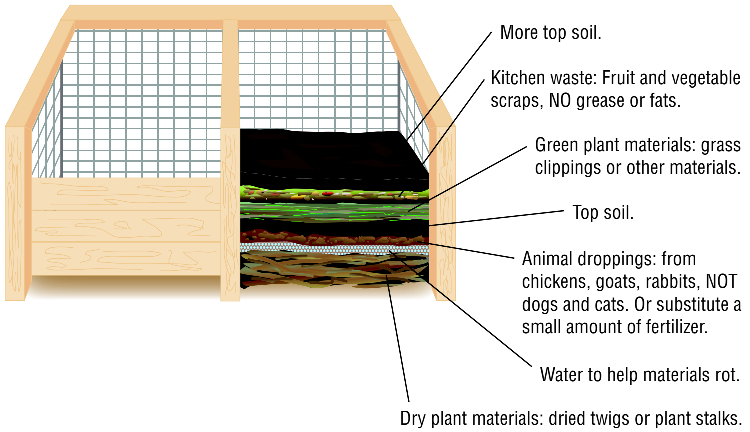
of decay. Soil organic matter includes such things as leaves, roots, sticks, microorganisms, fruit, seeds, worms, insects, animal remains, manure, and food scraps. The decomposition of organic matter gives soils extra nutrients needed by plants to grow strong and healthy. It also improves the structure of the soil and helps the soil stay moist. Soil organic matter that has fully decomposed is called humus, a dark brown spongy soil. On average, only about 5 percent of soil is soil organic matter.

Development

How organic fertilizers, like cow manure and seaweed, came to be used by humans to help grow plants is not known. However, it is known that, for example, when the colonists first arrived to the New World, a bony fish called the Atlantic menhaden was used by Native Americans to fertilize their crops. The menhaden usually swam near the shore, which made it easy for early colonists and Native Americans to catch them.

Organic farming became popular with gardeners and farmers starting in the 1940s. British agriculturalists Albert Howard, who

How to make compost


More top soil.
Kitchen waste: Fruit and vegetable scraps, NO grease or fats.
Green plant materials: grass clippings or other materials.
Top soil.
Animal droppings: from chickens, goats, rabbits, NOT dogs and cats. Or substitute a small amount of fertilizer.
Water to help materials rot.
Dry plant materials: dried twigs or plant stalks.

Keep the compost materials moist and turn the layers with a pitchfork or shovel to allow the compost to decay.

A backyard compost heap can be made with a variety of layered materials, kept moist, and turned regularly. *Illustration by GGS Inc.*

wrote the book *An Agricultural Testament*, and Eve Balfour, who wrote *The Living Soil*, talked about farming with natural fertilizers and the advantages and disadvantages of organic versus traditional (inorganic) farming. American researcher Jerome Irving Rodale began publishing the magazine *Organic Farming and Gardening* in 1942. About this same time, a group of American farmers encouraged natural farming. Russell and Kate Lord, as part of the group Friends of the Land, edited the book *Forever the Land: A Chronicle and Anthology*, a series of articles written by people involved with organic farming. These people and others helped to popularize organic farming and the use of organic fertilizer.

Current Issues

Controversy with the way organic farmers labeled their food occurred in the last half of the twentieth century. Regulations were not the same among the fifty states and various private certification programs. Because of these issues with organic products, including fertilizers, the Organic Foods Production Act was made into law in 1990. Consequently, the U.S. Department of Agriculture (USDA) established national standards for organic foods. However, these standards did not solve the problem. In 2002, the USDA established new standards through the National Organic Program. Standards such as “100 percent organic” must contain 100 percent

Making a Compost Pile at Home

Compost piles are classified as hot or cold. A hot compost pile is made by piling one part green organic matter (such as grass clippings) with two parts brown organic matter (such as dead leaves) into a container that is generally at least five feet wide at the bottom and three feet wide at the top. This amount of material lets the pile's center reach a temperature of 120 to 150 degrees Fahrenheit (49 to 66 degrees Celcius); hot enough to make compost. If the material is turned each week, then the compost will be made quicker, often within six weeks to two months.

The easier way to make a compost pile is with the cold method. Grass clippings, leaves, weeds, food scraps, and other materials are thrown into a pile. A minimum volume is not required because a certain temperature is not needed. The decay occurs on its own and at a slower rate, usually between six to twenty-four months.

organic ingredients and "organic" must contain at least 95 percent organic ingredients.

By 2006, USDA standards were still different from standards of more than forty private and state fertilizer certification organizations. In addition, the USDA does not regulate the labeling of organic foods. Instead, state fertilizer control officers with the Association of American Plant Food Control Officials provide this service. Consequently, organic farmers may mistakenly buy what they think is USDA-approved organic fertilizer. When this happens, the farmer may lose the right to sell organic products. To avoid troubles, organic farming groups are lobbying the various private and state organizations to modify their standards to match USDA standards.

Organic fertilizer does not usually contain as many nutrients as synthetic fertilizer. However, organic fertilizer has been shown to be just as good when compared to inorganic fertilizer because it releases its nutrients much more slowly into the soil. It improves the texture of soils, allowing water to move freely about. Organic fertilizer also helps to improve the environment by not adding chemicals to the soil.

Since organic fertilizers release their nutrients slower than inorganic fertilizers, when nutrients are needed quickly to produce big yields in crops, a much greater amount of organic fertilizer must be used. Thus, it costs more for materials and labor. It is also difficult to control the type and amounts of nutrients in organic fertilizers, which

Words to Know

Bacteria: Microscopic organisms whose activities range from the development of disease to fermentation.

Inorganic: Composed of minerals that are not derived from living plants and animals.

Nutrient: A substance that provides nourishment.

Organic: A term used to describe molecules containing carbon atoms.

makes it hard to match soil needs. For these reasons, organic fertilizers are used less in large-scale farming operations, but are used most often in gardens and small-scale farming operations.

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[*See Also* **Vol. 2, Agriculture; Vol. 2, Biological Crop Rotation; Vol. 3, Government Regulations; Vol. 2, Soil-Modifying Bacteria.**]

Corn, Genetically Engineered

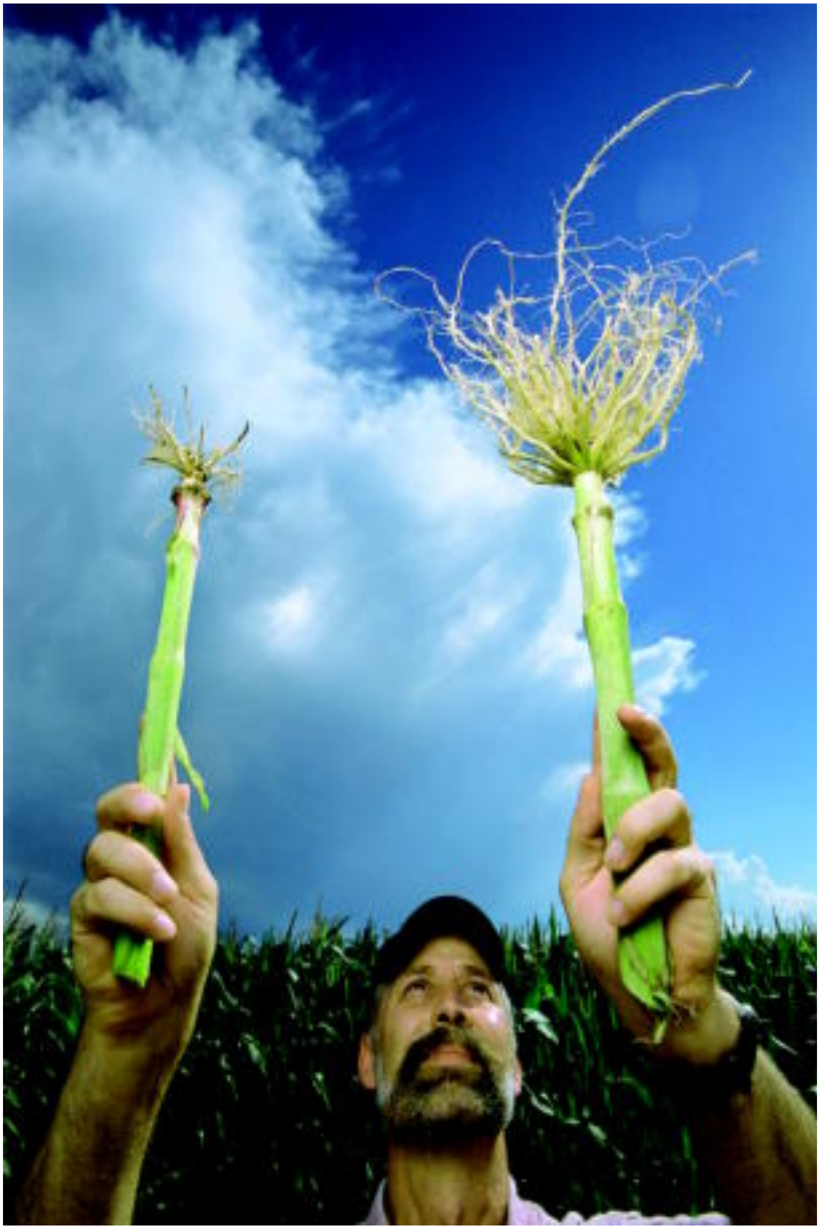
Description

Corn, also called maize, is a cereal grain. A cereal grain is any type of grass whose seeds are used for food. Genetically engineered corn, also called transgenic corn, is corn whose DNA (deoxyribonucleic acid, its genetic information) has been changed in the laboratory.

Corn is the largest crop grown in the United States, which also is the world's largest grower of corn. China is second, growing less than half the U.S. crop.

There are several kinds of genetically engineered corn. Two kinds of traits or abilities have been genetically engineered into corn, herbicide resistance and insect resistance. A herbicide is a chemical that kills plants, especially weeds. Farmers spray herbicides on many crops so that the crops do not have to compete with the weeds for water and soil nutrients. The most popular herbicide in the world is a chemical called glyphosate, which was invented by the Monsanto company in the early 1970s. Monsanto sells glyphosate under the trademark name Roundup®. Several crop plants, including corn, have been genetically engineered to be immune to Roundup. Fields of these crops—which Monsanto calls Roundup Ready® crops—can be sprayed with large amounts of glyphosate, and only the weeds will die.

Some plants, including some types of corn, have been genetically engineered to make a chemical in their leaves or other parts that is bad for some insects. The most common insect-resistant genetically engineered plants are the ones called Bt varieties. There is Bt corn, Bt cotton, Bt soybeans, and so forth. "Bt" stands for *Bacillus thuringiensis*, the scientific name of a bacterium (a very small, usually single-celled, organism). To make Bt corn, scientists took DNA from *Bacillus thuringiensis* and added it to the DNA of a corn plant. This Bt DNA tells the cells of the



Root growth of genetically modified corn, right, and nonmodified. © *Jim Richardson/Corbis.*

corn how to make a protein that is poisonous to some insects that eat corn plants. Since these insects cannot thrive on corn that makes the Bt protein, less of the pesticide usually used against them needs to be sprayed on a Bt corn crop. However, other pesticides must still be used on Bt corn or other Bt crops to kill other kinds of insects that are not harmed by Bt.

Lab technician removing kernels of genetically engineered corn for analysis. © *Lowell Georgia/Corbis.*

Scientific Foundations

DNA is the molecule used by all living cells to pass traits on to the next generation. DNA also acts as a recipe book for the cell to make the proteins it needs while it is alive. A gene is a short section of DNA that tells the cell how to make a single protein, a chemical the body uses to function.

Evolution or traditional selective breeding usually takes many generations to make a plant or animal with a new trait. Genetic engineering can make a new trait appear in a single generation. The trait might even come from a completely different kind of organism. For example, Bt corn and Roundup Ready corn have genes that came from bacteria.

Genes can be added to a plant's DNA using a device called a "gene gun." The gene gun takes tiny particles of metal (tungsten, silver, or gold) that are coated with copies of the gene to be added and fires them through the cell. Some of the new DNA stays in the cell and gets added to the cell's own DNA.

Development

Transgenic corn was first developed in 1988. It was not grown by farmers, however, until 1996. This transgenic corn was a Bt corn developed by the Ciba-Geigy company. Two other companies, Monsanto and Dekalb, were also trying to engineer Bt corn varieties.

Big Oops

In 2005, an unknown number of tons of genetically engineered Bt corn grown in the United States was sold to Europe by accident. The Europeans were not pleased, as the missing tonnage not only contained a type of genetically engineered corn called BT11, which they had agreed to buy, but another variety called BT10, which they had not agreed to buy. BT10 corn contains a gene that could, in theory, make some bacteria resistant to the antibiotic ampicillin. (Antibiotics are drugs that kill bacteria living inside an animal without harming the animal.) Most scientists thought that the chances of this happening were very small, but foes of genetic engineering said the issue was lack of control, not mass poisoning. A Greenpeace spokesperson said, ''This cases exposes the basic unpredictability of [genetically modified organisms], . . . the complete lack of regulatory controls in the U.S., and the lack of implementation of controls in the European Union.''

Monsanto and Ciba-Geigy (later re-named Novartis) fought legal battles for years, each claiming that the other had stolen their ideas (infringed on their patents).

In 1998, Monsanto started selling Roundup Ready genetically engineered corn varieties. By 2000, 25 percent of the U.S. corn crop was either Bt or Roundup Ready. By 2006, the figure was almost 50 percent.

Genetically engineered corn varieties that produce medical drugs also have been created, but these are not yet widely grown.

Current Issues

Most scientists believe that genetically engineered corn is safe, but some do not agree. Many people in Europe dislike the idea of genetically engineered food. Many people in the United States do too, but not as many. Opponents of genetically engineered corn and other transgenic crops are concerned that engineered genes might get into wild plants with unpredictable and uncontrollable results. They also say that people and food animals fed with the genetically engineered plants for long periods of time might not remain healthy. Genes from genetically engineered corn, which spreads its pollen on the wind, have also been known to get into the corn crops of farmers who do not want to grow genetically engineered corn at all, especially organic farmers. Organic farmers use no artificial chemicals or genetically modified organisms to grow food.

Most scientists are puzzled by the dislike many people have for genetically engineered foods. They point out that most scientific studies have found these foods are not harmful. Opponents of

Words to Know

Antibiotic: A compound produced by a microorganism that kills other microorganisms or retards their growth. Genes for antibiotic resistance are used as markers to indicate that successful gene transfer has occurred.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Insect resistance: The ability, possessed by some kinds of genetically engineered plants, to make a substance that is poisonous to insects.

Maize: Another word for corn, a cereal grain.

Organic farming: Farming that uses no artificial chemicals or genetically engineered plants or animals.

Transgenic: A genetically engineered animal or plant that contains genes from another species.

genetic engineering answer they are less worried about what has happened so far than about what might happen in the future. They wonder what will happen if genetic engineering continues and many kinds of plants are altered in many different ways and grown and eaten in large amounts. Many technologies, they say, have had bad effects that were not intended, and this could also happen with genetic engineering, a technology that can change the nature of life itself. Supporters of genetic engineering agree that there are risks, but insist that those risks are small and can be easily managed.

Genetically engineered corn is especially controversial in Mexico, the region where corn was first domesticated from wild plants thousands of years ago. Corn is revered in Mexico, where tortillas, tacos, tamales, and pozole are common foods. Many Mexicans resent the idea that their corn might be altered by American scientists without their permission. In 2004, the *New York Times* newspaper reported that an official group of scientists from Canada, the United States, and Mexico had found that "genetically engineered corn has made its way into Mexican fields from modified American seeds and could ultimately displace native corn varieties unless the government moves to protect them."

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[*See Also* **Vol. 2, Alfalfa, Genetically Engineered; Vol. 2, Cotton, Genetically Engineered; Vol. 3, Plant-Made Pharmaceuticals; Vol. 2, Rice, Genetically Engineered; Vol. 2, Terminator Technology; Vol. 2, Tomato, Genetically Engineered; Vol. 2, Transgenic Plants; Vol. 2, Wheat, Genetically Engineered.**]

Cotton, Genetically Engineered

Description

The cotton plant is a shrub that was originally found in Asia but is now grown around the world. Genetically engineered cotton is cotton whose DNA (deoxyribonucleic acid, its genetic information) has been changed directly in the laboratory rather than by breeding.

Cotton produces a capsule called a boll that contains a mass of fibers around its seeds. The fibers are harvested to make cotton thread or yarn that is woven or knit into cloth. More clothing is made from cotton than from any other kind of fiber. Cottonseed oil is pressed from the seeds and is used in many foods, including cookies, crackers, peanut butter, and salad dressing. The material left over from pressing oil from the cotton seeds is used as animal feed.

There are many varieties, or types, of cotton. Different varieties grow best in different soils and climates. Until recently, all cotton varieties were made by selective breeding. In this method, which is thousands of years old, farmers look for plants that have the best characteristics—the most fiber, say, or the best growth in dry weather. They then use seed from these plants to raise the next generation of plants. Over time, plants selected in this way become more useful. Genetic engineering is a quicker way of getting plants to have the characteristics that cotton growers wants.

As of 2006, about one-third of the cotton grown in the world and over 75 percent of that grown in the United States was genetically engineered cotton (also called transgenic cotton). There are several kinds of transgenic cotton. Some are immune to the herbicide or week-killer glyphosate, also called Roundup. (The brand name Roundup® is owned by the Monsanto company, which invented glyphosate in the 1970s.) Transgenic cotton that is

Worker in a test field of Bt cotton in India. © *Pallava Bagla/Corbis.*

immune to glyphosate is called Roundup Ready® cotton. Large amounts of glyphosate can be sprayed on a Roundup Ready cotton crop, killing the weeds but not the cotton. Not having to compete with weeds helps the cotton plants grow better. Types of transgenic cotton that are immune to herbicides other than glyphosate have also been made.

Another kind of transgenic cotton is Bt cotton. Bt is short for *Bacillus thuringiensis*, the scientific name of a species of bacterium (a very small, usually single-celled, organism). To make Bt cotton, scientists took a gene—a section of DNA that tells a cell how to make a single chemical—from the DNA of the *Bacillus thuringiensis* bacterium and added it to the DNA of a cotton plant. The substance made by the Bt gene is a chemical that is poisonous to some insects that eat the cotton boll, particularly the pink bollworm, tobacco budworm, and cotton bollworm. Since these worms do not thrive on cotton that makes the Bt chemical, less of the pesticide usually used to kill them is sprayed on a Bt cotton crop. However, other pesticides must still be used on Bt cotton to kill other kinds of insects.

You're Wearing It

Chances are, you're wearing cotton right now—underwear, shirt, pants, or skirt. If you are, then that piece of clothing almost certainly contains genetically engineered cotton. Over three-fourths of the cotton grown in the United States (and, as of 2006, about one-third of the cotton grown worldwide) is some genetically engineered variety. What's more, you've almost certainly eaten transgenic cotton in the form of cottonseed oil, which is used in many processed foods such as cookies, crackers, and some peanut butters. For good, bad, or both, it's already a transgenic world.

Scientific Foundations

In genetic engineering, the DNA of a plant is changed in the laboratory. DNA is a long molecule found in all living cells. It contains information, much like a computer's memory does. This information is used to pass traits on to the next generation and as a recipe book for the molecules that the cell needs to make while it is alive.

Genes can be added to a plant's DNA by shooting them out of a device called a "gene gun." The gene gun takes tiny particles of metal (tungsten, silver, or gold) that are coated with copies of the gene to be added and fires them through the cell. Some of the new DNA stays in the cell and gets added to the cell's own DNA.

Development

The fact that some Bt bacteria are harmful to moths and butterflies in their larval (worm) stage of life was discovered in 1901 by a Japanese biologist named Shigetane Ishiwatari. The specific chemical that makes Bt bacteria harmful to some insects, however, was not discovered until 1956. In the late 1950s, American farmers began using the Bt chemical as an insecticide (insect-killing chemical).

The first transgenic cotton created was a Bt cotton called Bollgard, first sold to farmers by Monsanto in 1996. The same year, Monsanto also sold its first type of Roundup Ready® cotton. Starting in 1998, Monsanto released cotton varieties that were resistant to both glyphosate and bromoxynil, another weed-killer. By that time, half of the U.S. cotton crop was genetically engineered cotton.

Today, about half of the genetically engineered cotton grown in the United States is herbicide resistant and the other half is Bt (or Bt plus herbicide) resistant. As of 2006, Monsanto's Bollgard cotton was being

Words to Know

Bioballistic method: The shooting of tiny DNA-coated metal bullets into cells as part of the genetic engineering process.

Bt: Short for *Bacillus thuringiensis*, a kind of bacteria. Genes from Bt bacteria have been added to the DNA of some genetically engine ered plants, including corn and cotton, to make them resistant to certain insects.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Gene gun: A device that shoots tiny metal bullets coated with DNA fragments into cells in order to alter their DNA permanently.

Glyphosate: A weed-killing chemical; the world's most-used herbicide.

Pesticide: A chemical meant to kill plants or insects that hurt crops.

grown in Argentina, Australia, Canada, China, Colombia, India, Indonesia, Japan, Mexico, the Philippines, and the United States.

Current Issues

As with all genetically engineered crops, people disagree about whether it is wise to grown genetically engineered cotton. Most scientists believe that genetically engineered plants are safe, but not all.

Government and industry sources state that transgenic cotton allows farmers to reduce their use of pesticides and grow more cotton. Critics claim that these claims are wrong or misleading. In the United States, some farmers have successfully grown transgenic cotton, but other farmers have not been as successful. In 1998, some farmers blamed Monsanto's Bollgard cotton for crop failures, whether correctly or not. In 2006, over ninety Texas cotton farmers sued Monsanto, claiming that the Roundup Ready cotton they planted was not ready for Roundup at all under conditions of high heat and scarce water, but was killed by the herbicide.

The same ecological worries are raised by transgenic cotton as by other transgenic crops. Critics fear that engineered genes may contaminate wild species of plant. The environmental group Greenpeace, which opposes genetic engineering, claims that Chinese state-owned science institutes have found that the main pests targeted by Bt cotton are quickly building up immunity to the Bt protein. If true, this may lead eventually to the use of more pesticides rather than less. The Chinese researchers also claim that pests not targeted by Bt, such as cotton aphids and cotton spider mites, have increased since Bt cotton began to be raised, forcing farmers to use more of some pesticides. Greenpeace claims that the Chinese research shows that Bt cotton "will be ineffective in controlling pests after eight to ten years of continuing production." Since genetically engineered cotton is already being grown in large amounts in many countries, the next ten to fifteen years should show whether these claims are correct.

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[*See Also* **Vol. 2, Corn, Genetically Engineered; Vol. 2, Rice, Genetically Engineered; Vol. 2, Terminator Technology; Vol. 2, Transgenic Plants; Vol. 2, Wheat, Genetically Engineered.**]

Disease-Resistant Crops

Description

Plants do not have an active immune system, as people do. They do have some built-in protection, for example, the ability to release substances that make them taste bad if eaten. But plants cannot protect themselves well when attacked by bacteria (tiny, one-celled organisms that cause disease), fungi (plant-like organisms that feed off of other organisms), or viruses (small organisms that can multiply in a host cell and cause disease). These tiny organisms can cause diseases that either damage plants or introduce toxins (poisonous substances) that make them dangerous to eat. Since humans need plants for food, they want to keep them as healthy as possible.

One way to protect plants is with chemicals, but these can be harmful to the environment. Also, chemicals do not work well against some types of disease-causing organisms.

Another way to protect crops against diseases is to change their genes in a laboratory. Scientists can introduce a gene into a plant that protects it against disease. The process works somewhat like giving the plants a built-in vaccine (a medicine that gives immunity against a disease).

Scientific Foundations

All plants (as well as animals) contain genes. Genes are like a recipe book that tells cells how to make certain proteins. Which proteins are produced determine which traits the plant will have. The complete set of genetic information in the plant is called its genome.

Plants normally pass along their genes through pollination, the transfer of pollen from the male part of the plant to the female part of the plant to fertilize it. But scientists have learned how to

Lab workers studying disease-resistant vegetables in Bangalore, India. © *Robert Wallis/Corbis.*

identify the genes that code for desirable traits, such as disease resistance, and transfer those genes to a plant. Scientists can take the desired gene from another plant, or another species, such as bacteria or viruses. The transported gene is called a transgene. It becomes a permanent part of the plant's genetic material. The plants that are produced as a result of this gene transfer are called transgenic, or genetically modified, plants.

Development

In the 1940s, an American plant scientist named H. H. Flor (1900–1991) was working with flax plants when he made a discovery. For every gene in the flax plant that caused disease resistance, there was a corresponding gene in the disease-causing organism. This was called the gene-for-gene theory. Later, it was discovered that the protein products of each of these genes interact with one another, leading to disease resistance in the plant.

The process of genetic engineering was discovered in the early 1970s. This made it possible for scientists to transfer genes from one species to another. The techniques for creating disease-resistant

The Potato Famine

In the 1800s, potatoes were a staple of the diet in Ireland because they were cheap and readily available. But in 1845, a fungus called *Phytophthora infestans* spread quickly among the potato crops. The disease killed not only the potatoes that were in the ground, but it also destroyed the potatoes that had already been harvested and were in storage. Without any way to protect the potatoes from disease, all of the potatoes were wiped out. More than one million people died of starvation. Another two million people moved to Britain, the United States, and other countries to escape the famine. If a similar disease were to strike a food crop today, scientists would probably be able to genetically modify the crop to make it resistant to the disease.

crops were developed in the early 1980s. Scientists created tobacco plants that were resistant to a virus called tobacco mosaic virus (TMV). In 1987, scientists for the first time successfully genetically engineered a food crop—the tomato—that was resistant to a disease.

However, scientists still did not understand the way in which plants fought off disease. They slowly started uncovering the genes involved in disease resistance in the 1990s. This understanding helped them create disease-resistant corn, cotton, papaya, and other crops.

Today, scientists can genetically modify crops to make them resistant to bacteria, fungi, and viruses. First, they find the gene in another plant or species that codes for the disease-resistant trait. Then they copy the gene in a laboratory. They transfer the gene into the new plant's genome, using a type of bacteria or a gene gun to carry the new gene into the plant's cells. The new gene will protect the plant against the bacteria or virus, if it encounters them in the future.

Current Issues

A major advantage of genetically engineering disease-resistant crops is that their use will protect against crop losses. More crops means more food to nourish the world's population. Also, planting disease-resistant crops will reduce the use of chemicals to kill fungi and other disease-causing organisms. Chemicals can be damaging to the environment.

One concern with making crops disease-resistant is the potential for the genes from genetically engineered plants to cross over into nearby plants. This could produce "super weeds" that are resistant

Words to Know

Bacteria: Microscopic organisms whose activities range from the development of disease to fermentation.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Genome: A complete set of the DNA for a species.

Pollination: Movement of pollen from the male reproductive organ to the female reproductive organ, usually followed by fertilization.

Toxin: A poison that is produced by a living organism.

Transgene: A gene from one organism that is inserted into the genome of another organism.

Vaccine: A product that produces immunity by inducing the body to form antibodies against a particular agent. Usually made from dead or weakened bacteria or viruses, vaccines cause an immune system response that makes the person immune to (safe from) a certain disease.

Virus: A very simple microorganism, much smaller than bacteria, that enters and multiples within cells. Viruses often exchange or transfer their genetic material (DNA or RNA) to cells and can cause diseases such as chickenpox, hepatitis, measles, and mumps.

to bacteria and fungi, and are therefore nearly impossible to destroy. It is also possible that the gene introduced into a plant could recombine with the infecting virus and create an even more dangerous strain of the disease. Or, fungi and bacteria could become resistant to the genetic modification, meaning that the plants would no longer be able to fight off the diseases.

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[*See Also* **Vol. 2, Bt Insect-Resistant Crops; Vol. 2, Drought-Resistant Crops; Vol. 2, Frost-Resistant Crops; Vol. 1, Genetically Modified Foods; Vol. 2, Herbicide-Tolerant Plants; Vol. 2, Salinity-Resistant Plants; Vol. 2, Transgenic Plants.**]

Drought-Resistant Crops

Description

Crops—plants that are raised for food—require an adequate supply of water for their survival and growth. The scarcity of rain that is the hallmark of a drought is a problem for crops, and for the people and animals who depend on the crop plants as a source of food.

Plants can adapt to changing environmental conditions naturally. However, this process often occurs slowly and not on a scale that will maintain the production levels of crops that are needed to feed the population of a country, continent, or planet. The techniques of biotechnology and genetic engineering—where target pieces of genetic material called genes can be isolated from one organism and deliberately introduced in a different organism—are being used to engineer plants that are hardier in drought conditions.

Scientific Foundations

Deoxyribonucleic acid (DNA) is the chemical substance in all living cells that passes on genetic characteristics from one generation to the next. Analyses of the DNA of organisms, including plants, can identify regions that code for the production of chemicals called proteins, that control most cell functions, or other molecules. These regions are called genes.

The genetic engineering techniques needed to create drought-resistant plants were developed in the 1970s and 1980s. Using these techniques, genes can be removed from the surrounding DNA using specific enzymes (chemical catalysts) that recognize certain DNA sequences and cut the DNA at those points. Appropriate

Seeds of drought-resistant plants stored and studied in Russia. If researchers can isolate a gene for drought-resistance in one plant, they can insert that gene into another plant with genetic engineering techniques. © *Steve Raymer/Corbis.*

enzyme selection produces fragments of DNA; some of the fragments contain the desired gene.

Using other enzymes, the DNA of the recipient organism can be cut in such a way that the gene-containing DNA fragment from the donor becomes part of the recipient DNA. Subsequently, the inserted gene will be under the genetic control of the recipient, and so will be expressed in the same way that the recipient's genes are expressed. (How a gene is expressed refers to how it functions, or does its job.) Once expressed, the new protein can perform its normal function in the new organism.

In a different approach, a gene that is normally present in an organism can be deliberately and specifically altered. This alteration can involve the replacement of one of the chemical building blocks that comprise the gene, which very often affects the way that the protein functions.

In the case of drought-resistant plants, several target genes have been identified and either altered in the plant or transferred from a different organism to the plant. For example, a gene called ERECTA controls the formation of channels (pores) on the surface

Global Warming and Drought-Resistant Crops

According to the Intergovernmental Panel on Climate Change, an agency that advises the United Nations, Earth has become warmer by 1.3 degrees Fahrenheit (0.7 degrees Celcius) from 1906 to 2006. By 3006, the atmosphere is expected to warm by at least 2.7 degrees Fahrenheit (1.5 degrees Celcius). Areas of the planet that experience drought will be even harder hit. Also, some scientists contend that global warming could have a negative effect even in areas that are currently productive, such as central North America.

The need to develop crops that resist drought conditions will become urgent, according to the World Bank, if the burgeoning global population is to be fed. Paradoxically, as some regions of the planet become drier, other regions will face increased flooding, necessitating improved flood control.

of some plants. Scientists have been successful in changing the expression of the gene so that plants, such as *Arabidopsis*, lose less water vapor from their leaves, while still being able to take in the carbon dioxide that they require for survival and growth. *Arabidopsis* is a member of the mustard plant family and is often used as a model in plant biology research. By striking the right balance between water loss and carbon dioxide acquisition, researchers intend to breed plants that continue to grow and thrive in drought conditions.

In another example, tomato plants can be engineered to increase their expression of a gene designated AVP1. The AVP1 protein is active in the development of the roots system of the plant. Increasing the expression of this gene can cause the plants to develop more vigorous root systems, which can increase their ability to acquire moisture from drier soil.

Development

Much of the work on drought-resistant plants remains developmental. Yet, the prospects for the commercial use of such plants are good. For example, researchers are confident that the alteration of pores in *Arabidopsis* will enable rice and wheat plants to be altered in a similar way, since these plants contain gene sequences that are similar to the ERECTA gene.

Research has shown that tomato plants that have been engineered to develop more vigorous roots grow better under drought conditions than their counterparts that express AVP1 in normal amounts. Hopefully by identifying genes that perform a similar

Words to Know

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Drought: A prolonged and abnormal shortage of rain.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Genetic engineering: The manipulation of genetic material to produce specific results in an organism.

function in other plant species, these species also can be engineered for drought resistance.

Scientists are actively studying plants that grow well in drought conditions to identify genes that are expressed and not expressed during growth. An increased understanding of plant behavior during drought could lead to the exploitation of drought-critical genes in crop plants. Already one such gene, which encodes for an enzyme called aldehyde dehydrogenase, has been identified.

Corn, rice, wheat, and soybeans are targeted for the development of drought-resistant varieties. Companies like Bayer, Syngenta, Dow, and Dupont are actively researching drought-resistant plants. Monsanto—a company that is considered the leader in development of plants that are resistant to drought and other harsh environmental conditions—intends to have drought-resistant plants approved for use by 2010.

Current Issues

The use of genetically engineered plants can be a concern. Some people fear that the engineered plants will spread their genetic traits to other plants, both domestic and wild. As of 2006, with over a decade of experience in the commercial growth of genetically modified crops, this concern is fading.

Another issue involves the design of plants that express certain genes only under certain conditions (such as when a particular nutrient is supplied). This so-called genetic use restriction technology (GURT) could place food in developing nations under the control of for-profit companies, critics argue, since the pollen or seed of the crop plant would be sterile. Only by purchasing new seeds would drought-resistant plants be available in each growing season.

Somewhat tempering this concern is the knowledge that drought-resistant plants can increase crop yields, enabling more people to be fed. If the current pattern of global warming continues, the use of drought-resistant plants may become essential.

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[*See Also* **Vol. 2, Agriculture; Vol. 2, Frost-Resistant Crops; Vol. 2, Transgenic Plants.**]

Dyes, Plant-Based

Description

For thousands of years, natural dyes have been the source of colorings for a wide variety of applications, especially fabrics and foods. Many of these natural dyes come from plants. For instance, juniper berries, sumac leaves, and walnut shells are a good source of the color brown; iris roots yield black; roses and strawberries produce pink; and the bark of a red maple tree can be used to make purple.

Plant-based dyes are extensively used to color cotton, wool, and other natural yarns. Dyed yarns are used for many purposes, including weaving, knitting, and other forms of needlework. Natural dyes also are used in handicrafts, such as decorating Easter eggs, making tattoos, creating artworks of ethnic design, and making face paints.

Plant-based dyes are friendly to the environment. They are made from renewable resources, and most of them do not harm the skin or the environment. Compared to chemical dyes, natural dyes are inexpensive to produce. However, extracting color from plants is time consuming, and the process is messy.

Scientific Foundations

Colors are usually extracted from plants by soaking and boiling the appropriate plant part in hot water. Plant cells have pigments that give the plant its color or colors. At high temperature, these pigments break, releasing the color. Consequently, the hot water takes on the color of the pigment.

The quantity of dye extracted depends on a variety of factors including the location where the plant is grown, the climate, and the growth of the parts used. Flowers in full bloom, leaves collected

A plate of ingredients used to create natural vegetable dyes. © *Earl and Nazima Kowall/Corbis.*

in spring, and bark and roots gathered in fall are ideal for maximum color extraction.

Natural dyes require the addition of a fixative to permanently bind the color to the fabric. Fixatives such as alum and common salt are substances that slow down the evaporation rate, thus helping to bind the color for a longer period. Without a fixative, dyeing is temporary and the color will "bleed" out of the fabric the first time it is washed.

Development

Dyes have been used for thousands of years, especially in Asian countries. It is thought that natural dyes were being used in China in 2600 BCE. One of the oldest natural dyes, indigo, was used in India more than four thousand years ago. This dye was introduced to the rest of the world only after Portuguese explorer Vasco de Gama (1469–1524) traveled to India in 1498. Soon, indigo traders prospered because indigo was preferred to woad, the dye derived from a flowering plant that Europeans previously used to produce a blue color.

Different Countries, Different Dyeing Techniques

Batik, originating in the Indonesian island of Java, creates designs on fabric using wax. The design is painted on white cotton fabric with melted wax. The fabric is then dyed to add color and dipped in boiling water to remove the wax. The areas painted with the wax remain white.

Tie-dyeing, a technique from India, involves tying tiny areas of white fabric with pieces of cotton thread. After the fabric has been tied according to the pattern, it is dyed and dried. Later, the fabric is hand-stretched to open the tied parts giving a contrast of white with the dye color.

In those days, plant parts would be tied in a piece of cheesecloth and simmered in water. Eventually, the dyer would take out the cheesecloth bundle and add hot water to prepare a dye-bath. Over the years, the steps for dyeing have remained similar. However, the proportion of plant parts to water, as well as the duration the plant parts are simmered in water has changed with time.

Ever since people have been creating dyes, dyers have passed on their knowledge of dyeing from one generation to the next. Dyers had to be able to identify various dye plants, and had to understand their characteristics, the color they imparted, and the proportions in which they could be mixed to get the desired dyes.

The beginning of the nineteenth century saw the emergence of chemical dyes. Chemical dyes were cheaper than natural dyes, and they soon became more popular. A good example is indigo dye. After the development of chemical dyes, indigo dye began to be made synthetically rather than from the indigo plant. The most common use of synthetic indigo dye is in the denim industry to give blue jeans their distinctive color.

Current Issues

Although they are still very popular, some people are becoming concerned about the harmful effects of chemical dyes. Consequently, consumers are increasingly asking for products made with natural dyes even though mass production has made chemical dyes cheaper.

However, there are some limitations with plant-based dyes. People interested in making plant-based dyes may find it difficult to find the exact plants needed to make the required color. The problem can be partially resolved by collecting the target plant material whenever and wherever it is found. Some common dye

Words to Know

Batik: A method of dyeing cloth where areas are covered with substances that keep dyes from penetrating in order to make patterns.

Fixative: A substance that is used to bind dye to a fabric.

Woad: A blue dye obtained from the woad plant.

plants, like indigo and madder, also can be cultivated to ensure a ready supply. Experimentation with different parts of a variety of plants is required to create new colors.

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Fat Substitutes

Description

A fat substitute is a substance that tastes like a fat or an oil but with fewer calories. Calories are units of food energy; the more calories a food has, the more it tends to make the person who eats it gain weight. A person can eat more food that is low in calories without gaining as much weight. Fat substitutes are used to make low-calorie versions of foods like corn chips, ice cream, and salad dressing.

There are three kinds of fat substitutes. Some are chemicals that cannot be digested, even though they look and feel like ordinary oil. These substances are made from fat in laboratories. (Chemically, oil and fat are the same thing.) The most famous fat substitute of this kind is called Olestra®. This kind of fat substitute is used to make foods feel like they contain fat when tasted. Food experts call this property of food "mouth feel." Olestra has been used to make fried foods like potato chips because it has the mouth feel of cooking oil.

The second kind of fat substitute is a substance that feels rich and creamy, but it contains carbohydrates instead of fat. (Carbohydrates—like sugar and starch—are substances found in many foods. Carbohydrates have calories too, but not as many as fat.) These fat substitutes are used to help many low-fat processed foods stay moist or pour slowly. Low-fat frozen deserts, salad dressings, sauces, and baked goods, like cakes and pies, can be made with these carbohydrate fat substitutes.

The third kind of fat substitute is made from protein. Protein is a food substance found mostly in nuts, milk, eggs, and meat. The protein used to make fat substitutes comes from milk and egg whites. To make the protein into a fat substitute, it is separated

MADE WITH
Olean®
BRAND FAT-FREE COOKING OIL

Olean® potato chips, made by Frito Lay, uses olestra, a fat substitute. © *James Leynse/Corbis.*

from the milk and eggs and made into a fine powder. The particles of the powder can be mixed with water without dissolving or sticking to each other. These powders can be used to make creamy substances that feel almost like they have fat in them. The most famous fat substitute of this kind is called Simplesse™. Simplesse is used mostly in low-fat ice cream.

Scientific Foundations

The molecules (clusters of atoms) in Olestra are very similar to those of real fat. In fact, they are made from fat. But Olestra molecules are too large for the human body to break down into smaller chemicals that can pass into the blood and be used by cells. The chemicals that the human body uses to digest the fat molecules in ordinary food simply do not work on Olestra. Olestra passes right through the body and is excreted without being chemically changed. Since it is not digested, it cannot add to a person's weight. Other fat substitutes are digested, but do not have as many calories as fat.

Development

In the 1960s, researchers at the Proctor & Gamble company were looking for a way to help premature babies—babies that are born too soon—digest more fat. The goal was to help the babies gain weight. Instead, the researchers found a way to help some people gain less weight: they discovered Olestra. But it was many years before Olestra appeared in stores. The United States Food and Drug Administration,

Olestra: The Fight Goes On

The consumer group Center for Science in the Public Interest has been fighting Olestra™ since the early 1990s. The organization claims that Olestra causes some people to have sudden, painful bowel movements. ''If you're going to buy Lay's Light, Ruffles Light, or Doritos Light''—all snacks that contain Olestra—''you also might want to stock up on Cottonelle, Quilted Northern, or Charmin [toilet paper]—and plan not to stray to far from the bathroom,'' a representative of the group said in 2004. In 2006, in response to a lawsuit threatened by the group, the Frito-Lay company agreed to put an easier-to-read notice on its Light line of potato and corn chips saying that the chips contain Olestra. Frito-Lay also agreed to donate $150,000 to the Harvard Medical School to fund studies of nutrition.

which must approve all substances before they can be added to food, approved Olestra in 1996. Low-fat potato chips fried in Olestra have been sold across the country since 1998.

The Nutrasweet Company—which also makes sugar substitutes—started developing Simplesse in 1979. The product was ready to sell in 1988. In 1990, the Food and Drug Administration gave approval for Nutrasweet to start selling Simplesse. It is unusual for a new food additive to be approved in only two years. Approval was fast because Simplesse is made out of substances already found in foods. Olestra took longer to approve because it is an entirely new chemical not found in nature.

Current Issues

Fat substitutes based on carbohydrates and proteins, such as Simplesse, have been accepted with little trouble. Olestra, however, has been argued about a great deal. When it first appeared in foods in 1998, the Food and Drug Administration required that foods containing it, such as potato chips, have a warning printed on their package that said "Olestra may cause abdominal cramping [stomach pains] and loose stools." In 2003, the government said that the warning was no longer necessary, and it stopped appearing on packages. The Food and Drug Administration has received more than 20,000 complaints from people who said that Olestra made them sick, more than it has received for any other food additive. Stomach cramps and diarrhea are the most common complaints.

The American Heart Association, a private group that tries to reduce how much heart disease people suffer, has said that the

Words to Know

Calorie: The amount of energy obtained from food. The number of calories needed daily is based upon a persons age, gender, weight, and activity level.

Carbohydrate: Compounds that contain carbon, hydrogen, and oxygen. A carbon-containing compound that forms the supporting tissues of plants. Found in abundance in foods made from grains.

Fat substitute: A substance that feels like fat or help foods feel like they contain fat.

Fats: Substances found in many plant and animals tissues: chemically, esters of glycerol with fatty acids. An oil is a fat that is liquid at room temperature.

Protein: Complex molecules that cells use to form most of the structures and control chemical reactions within a cell.

"cumulative impact of using multiple fat substitutes as they increase in the marketplace is unknown." It adds that if a person's diet is otherwise healthy, "fat substitutes used appropriately can provide flexibility with diet planning."

Simply eating fewer snack foods and desserts reduces the number of calories in a person's diet. Making different food choices can have the same effect on weight as eating foods containing fat substitutes.

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[*See Also* **Vol. 2, Sugar Substitutes.**]

Food Bioprocessing

Description

Bioprocessing refers to the use of living microorganisms or their parts to produce a product. (Microorganisms are living things that are too small to be seen without a microscope, like bacteria.) In the case of food bioprocessing, the product is able to be eaten by people.

Scientific Foundations

Food bioprocessing is ancient. The use of microorganisms to make cheese, beer, wine, yogurt, and bread stretches back centuries. Bacteria (one-celled microorganisms) and yeast (a one-celled type of fungus) have long been employed to make useful foods. As an example of this antiquity, the term bridal is derived from the brewing of “bride’s ale” to celebrate weddings in England more than 500 years ago.

A process known as fermentation is used in the preparation of bread, beer, and wine. During fermentation, yeast breaks down the natural sugars present in foods into carbon dioxide and alcohol. Carbon dioxide is the gas that makes beer bubbly and bread dough fluffy. Alcohol is baked away in bread, but retained in beer and wine. Cheese-making and yogurt-making employ bacteria to produce these milk products. As bacteria grows in milk, it changes the nature of milk, making it thicker and more sour. Yogurt and, especially, cheese take longer to spoil than does fresh milk, allowing people to store these food products for times when milk was scarce or hard to carry.

Starting in the twentieth century, food bioprocessing was used in commercial operations to enable the production of large quantities of particular foods. In addition, the techniques of bioprocessing

The Ancient Lineage of Food Bioprocessing

Wine-making dates back at least 7,000 years. Pottery jars containing wine have been recovered from a 7,000-year-old house in northern Iran. Coincidentally, the manufacture of pottery is also thought to have begun at about the same time. Thus, one of the earliest uses of pottery vessels was to store wine.

It was not until centuries later that the basis of wine-making was fully understood. This research, conducted by French chemist Louis Pasteur (1822–95) in the 1860s, determined how fermentation works and how to keep wine from going sour. These observations led Pasteur to propose that microorganisms were responsible for other phenomena, leading to his ‘‘germ theory’’ of disease. This theory became one of the fundamental underpinnings of the scientific discipline of microbiology.

have enabled microorganisms to be tailored for more efficient production of a particular food.

Development

The manufacture of commercial quantities of bioprocessed foods has been made possible by the use of huge vats called bioreactors. The vats hold thousands of gallons of liquid, similar to the vats used to brew beer. Nutrients can be added to the culture of bacteria, yeast, or other microorganisms at a controlled rate. In some designs, the finished product can be withdrawn at the same rate. Other reactors are emptied when the product has formed, and new ingredients are added for the next production run. Factors such as temperature and a measure of the chemical nature of the product, called pH, can also be controlled. The result is a product whose quality and composition is both known and consistent from batch to batch.

The design of a bioreactor allows the microorganism to be maintained in the desired mode of growth. For example, bacteria growing and dividing at a maximum rate can be advantageous since the production of their components, such as proteins, is also at its peak. Proteins are chemicals used by living cells to control most of their functions. Sometimes the techniques of genetic engineering to place one organism’s genetic material (DNA, deoxyribonucleic acid) into another organism’s, often a type of bacteria. With the new DNA, the bacteria can produce proteins that they normally would not. When the bacteria reproduce, more of the foreign proteins are produced too, and scientists are able to extract these proteins from the bacteria to create a desired product.

Words to Know

Bacteria: Microscopic organisms whose activities range from the development of disease to fermentation.

Bioprocessing: The use of microorganisms to produce a desired end product.

Bioreactor: A container used for bioprocessing.

Fermentation: The process of breaking down sugar without oxygen into simpler substances, commonly alcohol and carbon dioxide.

Protein: Complex molecules that cells use to form most of the structures and control chemical reactions within a cell.

Yeast: A microorganism of the fungus family that promotes alcoholic fermentation, and is also used as a leavening (an agent that makes dough rise) in baking.

One example of food bioprocessing is the enhancement of proteins, vitamins, and iron in cereals. This can involve the activation of chemicals already present in the raw material, genetic modification of the material so that desirable chemicals are produced, and the use of certain bacteria (such as lactic acid bacteria) to introduce beneficial compounds to the manufactured cereal. The improved nutritional quality of the food is particularly important in underdeveloped countries.

Another example is the use of a fungus called *Fusarium venenatum* to make a protein called Quorn®. With the addition of some flavoring and coloring, Quorn can be used as a meat substitute in hot dogs and other products.

Current Issues

Research continues to explore how bioreactor growth conditions influence microorganism activity. The intent is to make the bioreactor process even more efficient and predictable, since product consistency and quality over time is important. In addition, the traditional food bioprocessing uses, such as the manufacture of beer, wine, and cheese, continue to be refined and improved.

An ever-present concern about bioprocessing is that the growth conditions and/or microorganism used could produce an undesirable or unhealthy compound unintentionally. Further research will increase the understanding of bioprocessing conditions and should help to minimize this concern.

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[*See Also* **Vol. 2, Beer-Making; Vol. 2, Bread-Making; Vol. 3, Fermentation, Industrial; Vol. 2, Wine-Making; Vol. 2, Yogurt-Making.**]

Food Preservation

Description

Food preservation, as the name suggests, is the process of preserving food to maintain its properties and prevent rotting. Dried herbs—commonly used as spices—are an excellent example of preserved food. Other examples include dried fruits, frozen vegetables and meats, pickles, jams, tomato paste, purees, yogurt, canned vegetables, and cheeses.

Preserving food reduces the amount of food that is wasted through spoiling. It involves a variety of techniques to store excess quantities of food, and these preservation techniques help to prevent food-borne diseases that may come from contamination or spoiling. Some food preservation techniques, like canning and freezing, protect food from animal pests, such as rodents, weevils, and beetles. Food preservation allows most foods to be available year-round rather than just when they are in season.

Scientific Foundations

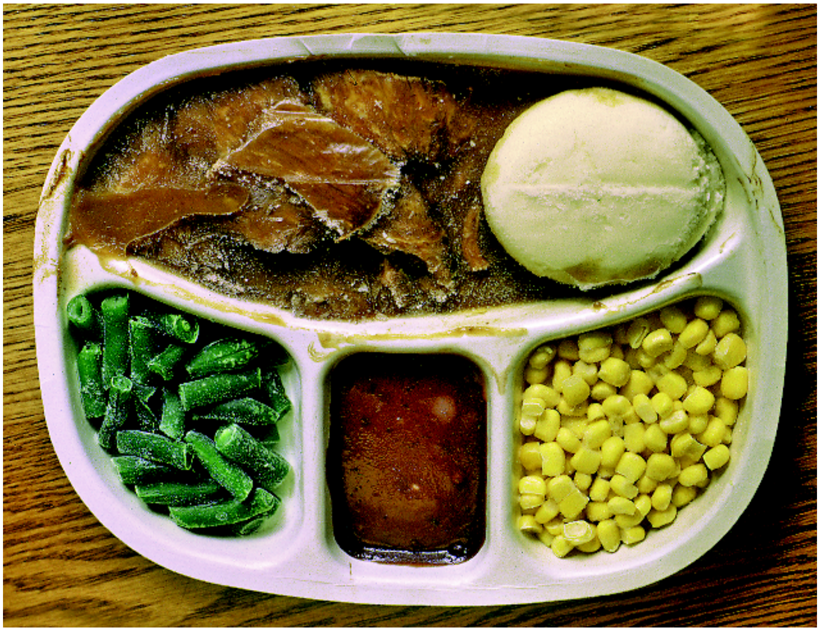
All food preservation methods prevent growth of microorganisms, living things that are too small to be seen without a microscope. Food preservation either kills them outright or makes the environment unfavorable for their multiplication. Heating foods to high temperatures kills most microorganisms, but it also cooks the food. Consequently, foods that need to be preserved in a raw or semi-cooked state cannot be treated at high temperatures.

In such cases, making the environment unfavorable for the growth of microorganisms is the other preservation option. Like all living things, microorganisms have certain requirements, such as food and moisture, for survival. Their growth can simply be

Fish on a bed of salt, waiting to be smoked. Fish preserved this way are called kippers. *© Jacqui Hurst/Corbis.*

restricted by treating food with agents that remove one or all of the elements necessary for their survival.

Commonly used methods of food preservation are freezing, drying, canning, vacuum-packing, salting, using preservatives,



Freezing foods is one of the oldest ways humans have used to preserve them. Frozen dinners like this were invented in the 1940s. *Robert J. Huffman/Fieldmark Publications.*

cooking in sugar and alcohol, smoking, and curing. Drying, freezing, canning, and some other food preservation methods are usually carried out at home. Industries also employ these methods, in addition to some of the newer techniques or those under study such as irradiation with x rays or high-intensity light, ultrasound (high-frequency sound waves), modified atmosphere packaging, pulsed electric fields, and high hydrostatic (liquid) pressure.

The food industry also uses over thirty different enzymes (substances that speed chemical reactions) to preserve food. Among the first commercial food products produced by biotechnology was rennet, which contains an enzyme called chymosin, and is used in making cheese. Some of these enzymes, including chymosin, are now produced using genetic engineering techniques in a laboratory.

Development

Since prehistoric times, humans have preserved surplus food to ensure its availability during periods of scarcity. Freezing and drying, the simplest techniques of storing surplus food, are the first steps in food preservation. Studies show that drying food was common even in 1200 BCE. Even today, drying is used frequently, particularly for grains. Freezing shares a similar history. It is known that Arctic people stored seal meat in ice. Subsequently, people realized that mixing salt with ice produced better results.

The Dark Side of Canned Foods

Canned foods greatly improved the health of sailors on long voyages and allowed explorers to investigate remote areas of the world. For example, when English explorer John Franklin's (1786–1847) expedition set out in 1845 to find a Northwest Passage from Europe to Asia through North America's Arctic Ocean, it carried thousands of cans of meat, vegetables, and soup as part of its food supplies. Franklin and all of his crew died during the expedition. When the bodies of three crewmembers were found and exhumed in the 1980s, it was discovered that they were suffering from lead poisoning. The lead probably came from the metal that was used to seal the food cans. Although lead poisoning did not kill Franklin or his crew, it probably affected their stamina and may have impaired their judgment, thus contributing to the expedition's tragic outcome.

In the late eighteenth century, other methods for preserving foods, such as canning, developed in France during the reign of Napoleon Bonaparte (1769–1821), who wanted better ways to store food for the army. French inventor Nicholas Appert (1741–1841) was the first person to successfully preserve heated food in airtight jars. In 1804, he opened the world's first canning factory in Massy, France. At the time, people did not understand that high temperatures kill microorganisms and that airtight containers keep live microorganisms out of the food. It was only in latter part of the nineteenth century that the work of Louis Pasteur (1822–95), a French chemist, demonstrated the role of microorganisms in spoiling food and the elimination of these microorganisms by high temperatures. Then, people began to understanding the scientific principles behind canning. Vegetables, fruits, seafood, meats, stews, and soups are some of the common food items that are canned.

In 1862 Louis Pasteur invented another food preservation technique—pasteurization. It involves killing most microorganisms present in a food by heating it at high temperature. Pasteurization is an ideal method for preserving milk. In addition to milk, water, juice, eggs, sports drinks, and beer also can be pasteurized to increase their shelf life. The duration of heating is short enough to prevent cooking, but it does bring about certain changes in food composition.

In 1963, the German doctor Ing Karl Busch and his wife pioneered a new food preservation technology called vacuum packing. When

Words to Know

Antifreeze protein: In nature, antifreeze proteins (AFPs) help animals and plants living in extreme winters cope with extreme cold. AFPs prevent formation of ice crystals so the fluids within an organism do not freeze.

Antioxidant: A chemical compound that has the ability to prevent the oxidation of substances with which it is associated. Oxidation can damage cells.

Pasteurization: A method for treating milk and other liquids by heating them to a high enough temperature for a long enough period of time to kill or inactivate any microorganisms present in the liquid.

foods are vacuum-packed, they are stored in plastic bags or other containers from which the air has been removed. The foods retain their original color and flavor longer because bacterial growth is restricted by reducing the amount of oxygen in the package.

Current Issues

Increasingly, consumers are demanding natural preservatives instead of chemical additives and the use of technologies that preserve the original flavor, color, and nutritional value of the food. With advances in biotechnology, the food preservation industry has developed ways of preserving food while retaining its nutritional content. For instance, antioxidants are substances that occur naturally in all cells, saving them from the damaging action of various chemical reactions. Antioxidants can be added to foods in the form of citric acid, pectin, and rosmarinic acid, where they act as natural preservatives.

Freezing, one of the most common methods of preserving food, causes recrystallization of ice in which small ice crystals become large. Recrystallization lowers the nutritional value of frozen foods. Using DNA recombinant technology, antifreeze proteins (AFPs) have been extracted from fish living in the polar regions. When added to foods, AFPs prevent ice recrystallization, thus preserving the nutritional value. AFPs offer a cost-effective way of increasing the shelf life of frozen foods.

The U.S. Centers for Disease Control and Prevention (CDC) considers irradiated foods safe to eat when irradiation technology is properly used. Studies have shown that irradiated foods keep their original nutritional value, and do not become radioactive or contain or harmful chemicals. Although food irradiation has been approved in the United States for fruits, vegetables, grains, spices, poultry, beef, pork, and lamb, irradiated foods are more expensive and are not yet widely available in supermarkets. Critics say the food tastes different than food that is not irradiated and that not enough evidence exists to claim with certainty that the chemicals formed from the irradiated plastic packaging that covers the food does not cause cancer.

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[*See Also* **Vol. 2, Biopreservation.**]

Frost-Resistant Crops

Description

Certain plants grow well in a particular climate. For example, palm trees thrive in hot, humid weather. But extremes of hot or cold can be deadly to some plants. When the temperature drops below freezing, ice crystals can form on the leaves of some plants, causing them to die. This problem prevents farmers in cold climates from planting certain types of crops, such as wheat, and it can also shorten the growing season.

One way scientists have discovered to protect plants from frost is to modify their genes in a laboratory. Some animals, insects, and plants that live in very cold climates have genes that make them resistant to the harmful effects of frost. Scientists can take a gene from an animal, insect, or plant that has this trait, and transfer it to a plant that needs to be protected from frost. It is much like giving a plant its own built-in antifreeze.

Scientific Foundations

Genes are the instructions in a plant (or animal) that tell cells how to make certain chemicals called proteins. Which proteins are produced determine what traits the plant will have. The complete set of genetic information in a plant is called its genome.

Plants normally pass along their genes when pollen from the male part of the plant fertilizes the female part of the plant. This process is called pollination. Scientists have learned how to identify the genes that code for particular desirable traits, such as frost resistance. Once they know which gene codes for the protein that affects a trait, they can isolate it from one organism and transfer it

Natural Antifreeze

It may seem impossible for any animal or plant to be able to survive in the harsh Arctic winters, where temperatures can dip below −22 degrees Fahrenheit (−30 degrees Celcius). The reason that life continues to exist in extremely cold climates is because plants and animals that live there have built-in mechanisms that protect them from the cold. Scientists have discovered that icefish, Antarctic cod, and other fish living in the Arctic produce proteins that act like a natural antifreeze. These proteins bind to the surface of ice crystals and stop them from forming before they can freeze the fish's blood and delicate tissues. Australian scientists discovered a gene for a similar protein in an Antarctic plant called hair grass. They planned to use the gene to breed frost-resistant wheat and barley plants.

into another organism of the same or a different species. This process is called genetic engineering.

The transferred gene is called a transgene. It becomes a permanent part of the new plant's genetic material. Plants that are produced as a result of this gene transfer are called transgenic, or genetically modified, plants.

Development

In the 1800s, an Austrian monk named Gregor Mendel (1822–1884) discovered the process by which plants transfer their genetic material from one generation to another. His discovery helped plant scientists learn how to breed plants with certain selected traits.

In 1953, American biologist James Watson (1928–) and English biologist Francis Crick (1916–2004) identified the double-helix structure of deoxyribonucleic acid (DNA, the double-stranded molecule that carries an organism's genetic information). Their discovery made it possible for future scientists to cut and paste genes from one species to another. This process, called genetic engineering, was discovered in the early 1970s. In the early 1980s, scientists tested the first genetically modified crops—disease-resistant tobacco and tomato plants.

By the early twenty-first century, scientists had discovered frost-resistant genes in certain northern species of fish, plants, and insects. These genes code for proteins that bind to ice crystals and prevent them from growing large enough to kill the plant or animal. Having this protection helps these organisms survive in very cold climates.

Words to Know

Antifreeze: A substance that lowers the freezing temperature.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Gene gun: A device that shoots tiny metal bullets coated with DNA fragments into cells in order to alter their DNA permanently.

Genome: A complete set of the DNA for a species.

Pollination: Movement of pollen from the male reproductive organ to the female reproductive organ, usually followed by fertilization.

Transgene: A gene from one organism that is inserted into the genome of another organism.

Vector: A vehicle used to deliver foreign genes into another organism's DNA. Viruses are the most commonly used vectors.

Scientists can create frost-resistant crops by first identifying and isolating the gene that codes for the antifreeze protein from a fish, insect, or other plant that contains it. Then they copy the gene in a laboratory. They transfer the gene to the new plant either using a virus or bacteria as a vector (the vehicle used to carry a new gene into cells), or a gene gun (a device used for injecting genetic material into cells). The plant will then begin to express, or produce, the frost-resistant protein on its own.

Current Issues

The big advantage to producing genetically engineering frost-resistant crops is that they are hardier than normal crops. For example, wheat, corn, and other food crops with a frost-resistant gene could be grown in cold regions of the world where they would not normally grow. Creating crops that are frost-resistant can also extend the growing season, which could result in higher crop yields.

Those who oppose genetic modification say they are concerned about the effects these plants might have on the people who eventually eat them. They call genetically modified foods "frankenfoods," because they may contain genes from more than one species. They also worry that genetically modified foods are the first step on the path to creating genetically modified humans with selectively chosen traits.

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Genetic Engineering

Description

Genetic engineering is the direct, deliberate changing of the DNA of living things. It is called "genetic" because it deals with genes and "engineering" because that is what all efforts to change the world using scientific knowledge are called. Genes are segments of genetic material that contain recipes, or code, for the production of subtances called proteins. Living cells are largely made up of different types of proteins, and proteins control most cell functions.

Genetic engineering did not exist before the early 1970s. Since then, many plants, animals, and microorganisms (living things too small to see with the naked eye) have been genetically engineered. Genetically engineered organisms are also called genetically modified or transgenic. There are many reasons for genetically engineering organisms including:

Research. Some genetic engineering is done to learn more about how DNA works. For example, glow-in-the-dark mice and tobacco plants have been made by adding genes from fireflies to ordinary mice and tobacco plants. The only purpose of making these oddities was to learn more about DNA and genetic engineering itself.

Farming. Many attempts have been made to engineer useful genetic changes into plants and animals. As of 2006, the use of genetically engineered animals to make food was still experimental, but many kinds of plants had been genetically engineered to make them more profitable. Today, most of the corn, cotton, and soybeans grown in the United States are genetically engineered.

Medicines. Some plants and animals have been genetically engineered to get their cells to make substances that act as medicines or vaccines (drugs that prevent people from getting certain diseases)

Cloned plants in laboratory dishes. Cloning technologies are among the most important genetic engineering applications. © *Jonathon Blair/Corbis-Bettman.*

for human use. For example, in 2006 Russian scientists announced that they had engineered tomatoes to produce a vaccine to keep people from getting the virus hepatitis B.

Gene therapy. Many doctors hope that genetic engineering can be used treat some of the diseases that are caused by defects in DNA. For example, some people are born with a DNA defect that leaves them unable to fight off germs. Starting in 2000, doctors began treating a few cases of this disease successfully with gene therapy. However, gene therapy has not been entirely successful, and caused cancer in two patients during experimental trials.

Creating disease. Genetic engineering could, in theory, be used to make disease germs that are more deadly than any found in nature. These might be used as weapons. However, almost all the nations of the world have signed a treaty, the United Nations Convention on Biological Weapons (1972), promising not to create such weapons.

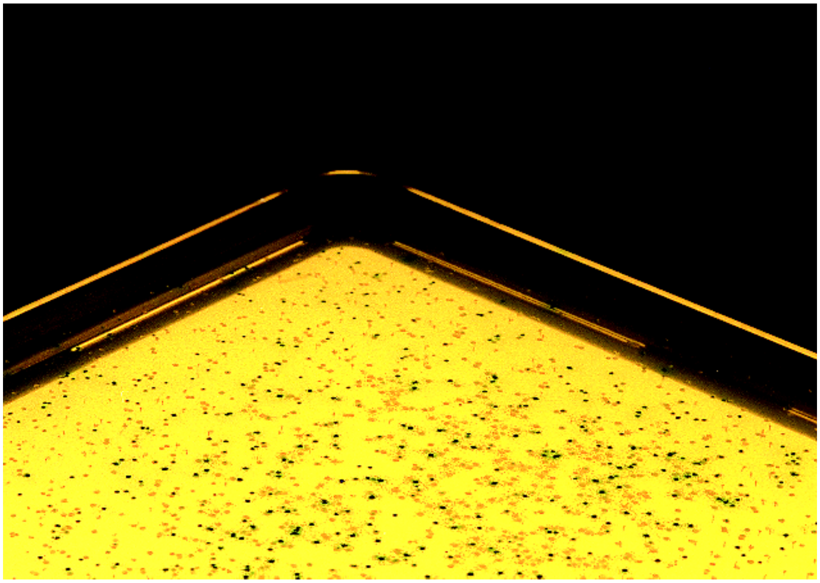

Plate of cloning bacteria used to duplicate DNA segments. Genetically engineered bacteria like these are used to mass-produce proteins that have medical or industrial applications. *Copyright Dung Vo Trung/CORBIS SYGMA.*

Eugenics. Some people believe that the human race could be improved through breeding or genetic engineering. They hope, for example, that children might be made taller or smarter.

Some people, including some biologists, believe that there are good reasons for not doing at least some kinds of genetic engineering. Many people disapprove of the genetic engineering of plants and food animals, and most people, including most biologists, dislike the idea of eugenics.

Scientific Foundations

Genetic engineering takes cells from a living organism and changes their DNA. New plants or animals can then be cloned, that is, grown to adulthood from those changed cells.

DNA (short for deoxyribonucleic acid) is a molecule or cluster of atoms shaped like a long ribbon or ladder, twisted many times along its length like a licorice stick. The rungs of this chemical ladder are small molecules or building-blocks that spell out a chemical message like a long line of letters. Cells read the DNA code like a book of recipes, putting together many different molecules that the cell needs to live. DNA is found in virtually every kind of living cell—bacteria, plants, and animals—and works the same way in all of them.

There are several ways to add genes to DNA. One is to shoot the genes into the cells using a kind of shotgun called a gene gun. A gene gun shoots tiny metal bullets coated with copies of a new gene through a cell. (In practice, many cells are shot at once.) Some of the gene copies stick inside the cells, and in a few cells the cell adds the gene to its own DNA. It is also possible to use certain bacteria and viruses to get new genes into the DNA of cells.

Genetic engineering is not an exact science. In most cases, scientists cannot control where in the cell's DNA the new genes get added. They may end up anywhere, with different effects. Even when a gene goes exactly where genetic engineers want it to go, it does not always do exactly what they want it to do.

Development

For many thousands of years, human beings have changed plants and animals genetically through selective breeding, which means choosing which individuals will make the next generation of offspring. This changes DNA over time, but it is not genetic engineering. Genetic engineering allows genes to be moved between completely different kinds of organisms, such as plants and animals, which was never possible before because such organisms cannot mate with each other.

Genetic engineering became possible in late twentieth century. In 1973, the first genetically engineered organism—a bacterium—was created. In 1980, the U.S. Supreme Court ruled that genetically engineered living things could be patented, that is, that the companies or persons who created them could demand money from anybody who wanted to grow them. Companies started developing genetically engineered organisms for profit. A substitute for the blood protein insulin that was made by genetically engineered bacteria was approved for sale by the U.S. government in 1982. The first time genetically engineered plants were grown in open fields was in 1986. In 1994, the Flavr Savr tomato, created by the Calgene company, was the first genetically engineered food sold in markets. In the 1990s, many plants, animals, and microorganisms were genetically engineered. By the early 2000s, scientists were developing more precise techniques to put new genes exactly where they want them in DNA.

Current Issues

Starting in the late 1990s, public opposition to the idea of genetic engineering—especially of plants and food animals—grew strong in some countries, particularly European countries.

Why do people argue so much about genetic engineering? Changing DNA changes the nature of living things—not just of a few individuals, but of all the descendants of those individuals,

The Common Cold to the Rescue

There can be mistakes in DNA, like misprints in a book. Sometimes, a DNA misprint makes the body's cells unable to produce a substance that the body needs. The result is often a serious disease, like muscular dystrophy, sickle-cell anemia, cystic fibrosis, severe combined immune deficiency (''bubble boy'' disease), or hemophilia. Scientists are learning how to treat such diseases by fixing the DNA in some of the patient's cells so that the body can make enough of the missing or defective substance. This is called gene therapy. In many kinds of gene therapy, a virus—a tiny particle of DNA surrounded by a protective envelope of small molecules, much smaller and simpler than a bacterium—is used to deliver new DNA to the patient's cells. The viruses most often used for gene therapy are the same kind that give us colds. Most people getting gene therapy with these viruses actually do get runny noses and sore throats along with the DNA the viruses are meant to deliver.

maybe forever. Also, genes from genetically engineered organisms may mix with those of wild species, changing them in ways that scientists cannot control or foresee.

The ability to change genes to produce desired characters or traits is a powerful new technology. There are potential applications of the technology, especially with regard to human life, that may conflict with religious and ethical beliefs in many societies. The appropriate use of genetic engineering is certainly an important social and political issue for many people.

There are also safety concerns about genetic engineering. Since scientists still do not know everything about how genes work, gene therapy has caused cancer or other unexpected side effects in some patients. Attempts at eugenics could create sick or deformed children if they failed and might have even more horrible consequences if they succeeded, dividing the human race into two classes—a superior, genetically-engineered class and everyone else. Ecologists and other biologists agree that there are ways in which genetically engineered plants might harm wild, natural communities of plants and animals (ecosystems). And then there is the struggle between farmers and corporations, who want to grow genetically engineered crops, and organic farmers, who want to keep their plants free of chemicals and engineered genes, since seed and pollen from genetically engineered crops have a tendency to mix with those of other fields. In Spain, genetic contamination of organic corn crops by genetically engineered corn crops has cost organic farmers large

Words to Know

Eugenics: A social movement in which the population of a society, country, or the world is to be improved by controlling the passing on of hereditary information through selective breeding.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Transgenic: A genetically engineered animal or plant that contains genes from another species.

Vaccine: A product that produces immunity by inducing the body to form antibodies against a particular agent. Usually made from dead or weakened bacteria or viruses, vaccines cause an immune system response that makes the person immune to (safe from) a certain disease.

Virus: A very simple microorganism, much smaller than bacteria, that enters and multiplies within cells. Viruses often exchange or transfer their genetic material (DNA or RNA) to cells and can cause diseases such as chickenpox, hepatitis, measles, and mumps.

sums of money because their corn, once it contains engineered genes, cannot be sold as organic.

Almost every month, stories related to the political and scientific debate over genetic engineering can be found in the newspapers. The morality, dangers, and benefits of genetic engineering are going to be argued about for a long time to come.

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[*See Also* **Vol. 1, Designer Genes; Vol. 1, DNA Vaccines; Vol. 1, Gene Therapy; Vol. 2, Genetic Pollution; Vol. 2, Genetically Modified Organisms; Vol. 2, Transgenic Animals; Vol. 2, Transgenic Plants.**]

Genetic Pollution

Description

Genetic pollution is any unwanted movement of genes from plants or animals raised by people to wild plants or animals or to other plants and animals raised by people.

People have been talking about genetic pollution since the early 1980s, when the first genetically engineered organisms were made in laboratories. Genetically engineered plants, animals, and microorganisms have all been created. A genetically engineered organism is a living thing that has had genes added to its DNA (deoxyribonucleic acid, its genetic information) to give it some property that some human beings want. For instance, one type of corn plant has been genetically engineered to make a drug in its tissues that can be harvested and purified. Other types of corn have been engineered to withstand certain herbicides, or weed killers.

Billions of genetically engineered plants are growing all over the world. The U.S. government has supported the development and use of genetically engineered plants, and says that their use is safe. Most biologists agree. There is also, however, opposition to genetic engineering from many citizens (especially in Europe) and from some scientists. These people believe that genetic engineering might harm crops, nature, and possibly human health.

Scientific Foundations

DNA is the molecule that all living things use to create offspring. It also serves a blueprint for making all the molecules that a cell needs during its lifetime. (There are only a few kinds of cells, such as red blood cells, that do not have any DNA.) Genetic engineering works

A field of genetically modified barley. Some groups fear that genetically modified plant products could blow to neighboring fields and contaminate non-modified plants. *Chris Knapton/Photo Researchers, Inc.*

by manipulating individual genes in an organism's DNA. A gene is a short length of DNA that tells a cell how to do a particular job.

Genetic pollution is a concern for plants and microorganisms (living things too small to see, like germs), but not for animals. This is because it is easy to control whether or not a domestic animal such as a goat, sheep, or cow, mates with a wild relative by confining the domestic animal in a barn. However, it is hard to stop plants that are growing in open fields from spreading their DNA.

Development

Genetic pollution has been possible ever since human beings bred some plants to be different from others. All plant breeding is a way of changing DNA. However, with genetic engineering, it is possible to make genetic changes that can never be made through selective breeding. For example, genes can be added to plants from animals or to animals from plants. Human genes have been added to rice; fish, insect, and bacteria genes have been added to plants.

The invention of genetic engineering technologies is truly new in human history. The structure of the DNA molecule was first understood in the 1950s, and the machines and knowledge to change DNA in the laboratory were developed little by little in the 1960s and 1970s. By the early 1980s, it was possible to genetically engineer plants, animals, and microorganisms, and people began to worry about possible future genetic pollution. In the late 1980s, genetically engineered crops were developed in laboratories. In the early 1990s, they began to be grown by farmers and sold to consumers. The discussion of genetic pollution continues in the 2000s, as genetically engineered crops are grown in ever greater numbers and varieties.

Current Issues

All biologists agree that genetic pollution can happen: what they disagree about is how often it is likely to happen and about whether it is likely to cause serious problems when it does.

There are reasons to think that genetic pollution will not happen often. For example, some important genetically engineered plants (such as soybeans) tend to be self-pollinating—that is, each plant shares genes only or mostly with itself during reproduction, not with other plants. And many biologists believe that when genetic pollution does happen, it will probably not do much harm because wild plants are already fitted to their way of life. Any change the wild plants, such as might be caused by genetic pollution, would probably make the polluted plants less fit—that is, less able to compete with their unpolluted relatives—so they would die out.

There are, however, objections to these ideas. First, some plants that are being genetically engineered do exchange DNA freely with wild plants that are genetically similar to them. In 2004, a scientific study

Stay Tuned to Your Local Tortilla

In Mexico, most people eat corn every day and small farmers raise hundreds of varieties of corn that have been shaped by centuries of breeding. Many Mexicans, therefore, are upset by the idea that genes from American laboratories might be sneaking into their corn. In 2001, the science magazine *Nature* published an article saying that transgenes—genes from genetically engineered plants—had been found in local varieties of Mexican corn. The report caused an uproar, but *Nature* quickly retracted (took back) the article because its evidence was not strong enough. In 2005, another science journal reported that there were no transgenes at all in Mexican corn, but this study was also criticized for not being based on good evidence. Scientists still did not know whether or not transgenes have become part of Mexican corn.

found that a new type of genetically engineered grass could spread its DNA to non-engineered grasses up to 13 miles (30 kilometers) away. What's more, this genetically engineered species of grass can cross-pollinate (share DNA with) twelve other species of grass.

Second, some plants may be more likely to share their DNA with wild plants after being genetically engineered than they were before. In 1998, scientists at the University of Chicago compared genetically engineered mustard plants that were resistant to an herbicide to non-engineered mustard plants. The non-engineered plants were also resistant to the herbicide, but their resistance had been developed by ordinary breeding. The scientists who did the study found that the engineered mustard plants were twenty times more likely to spread their genes for herbicide resistance to ordinary, non-resistant mustard plants than were the bred plants.

Finally, some scientific studies show that sometimes wild plants that gain new DNA from crop plants are no less fit than their wild fellows that do not have the new DNA. Movement of genes from non-genetically engineered crops to wild plants has already helped create tougher weeds that grow with seven of the world's thirteen most-raised crops, and there is no known reason why genetically engineered crops should not do the same thing.

Supporters of genetic engineering of plants argue that there are many benefits to this technology, and that these benefits outweigh the dangers. They argue that the new crops will save farmers money and be better for the environment. The debate between

Words to Know

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Herbicide: A chemical substance used to kill weeds or undesirable plants.

Transgenic: A genetically engineered animal or plant that contains genes from another species.

supporters and foes of genetic engineering is certain to continue for a long time to come.

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[*See Also* **Vol. 2, Cotton, Genetically Engineered; Vol. 3, Plant-Made Pharmaceuticals; Vol. 2, Rice, Genetically Engineered; Vol. 2, Terminator Technology; Vol. 2, Transgenic Plants.**]

Genetically Engineered Animals

Description

To genetically engineer an animal is to introduce new deoxyribonucleic acid (DNA, the double-stranded molecule of genetic material inside the cell nucleus) into its cells in order to give the animal a new trait. Animals could be genetically engineered to resist disease, produce more nourishing milk and meat for people to eat, generate organs that could be transplanted into humans, or produce food products (such as milk or meat) containing proteins that could help prevent or treat human diseases.

Scientific Foundations

All animals contain DNA, the double-stranded chain of genetic information that is held in the nucleus of every cell. DNA is made up of four chemical bases: guanine (G), thymine (T), cytosine (C), and adenine (A). Genes are sequences of these bases that code for specific proteins. (Proteins are the main components of living things.) Which proteins are produced determines which traits an animal will have. The entire set of genes in an animal is called its genome.

Genetic engineering involves finding and transferring the segment of DNA (called a gene) that codes for a particular trait from one organism to another. For example, scientists have genetically engineered goats with spider DNA so that they produce silk in their milk. They have also genetically engineered goats to produce human proteins in their milk, so that their milk can be used to treat diseases.

The DNA used for genetic engineering can come from the same species or from a different species. When the new gene is introduced,

The Treatment is in the Milk

Researchers have genetically engineered animals to produce drugs that could be used to treat human diseases. At the Roslin Institute in Scotland (the same research facility at which the famous cloned sheep, Dolly, was born), researchers engineered sheep with a human gene called alpha-1-antitrypsin. This gene enables the sheep to produce a protein in its milk that is lacking in people with cystic fibrosis and other lung diseases. Cystic fibrosis is an inherited disease that causes thick mucus (phlegm) to build up in the lungs. In other research, goats have been genetically engineered to produce milk containing a form of a protein that prevents blood clots from forming. The genetically modified milk could be used to help people who have a rare disease that makes their blood clot too easily.

it becomes incorporated into the animal's genome and causes the animal to exhibit that trait. An animal with DNA that has been taken from another organism is called a transgenic animal.

Development

One of the biggest breakthroughs on the path to genetic engineering was the discovery of the structure of DNA in 1953 by American biologist James Watson (1928–) and English biologist Francis Crick (1916–2004). Then in the 1960s, scientists discovered restriction enzymes. Restriction enzymes are special chemicals that can recognize and cut DNA at specific places so that scientists can separate out the gene they want to use. This led to the development of recombinant DNA technology, which is a technique for removing and inserting genes (called splicing) from one source to another.

In 1973, two American biochemists, Herbert Boyer (1936–) and Stanley Cohen (1935–), developed a technique of DNA cloning that allowed genes to be transplanted from one species to another. In 1980, the first transgenic mouse was born. By 1988, scientists had created transgenic rabbits, sheep, and pigs.

To genetically engineer an animal, scientists must first find the gene in another organism that codes for the protein they want. Then they use restriction enzymes to cut that gene from the rest of the DNA. They duplicate the gene in the laboratory. Then they insert the gene into the new animal.

The new gene can be carried into the new animal's cells using a tiny organism called a virus. Because viruses typically cause diseases

Words to Know

Cystic fibrosis: A fatal disease in which a single defective gene prevents the body from making a protein, cystic fibrosis transmembrane conductance regulator.

Ecosystem: A group of organisms and the environment they inhabit.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Embryo: A stage in development after fertilization.

Enzyme: A protein that helps control the rate or speed of chemical reactions in the cell.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Genetic engineering: The manipulation of genetic material to produce specific results in an organism.

Genome: A complete set of the DNA for a species.

Recombinant DNA: DNA that is cut using specific enzymes so that a gene or DNA sequence can be inserted.

Restriction enzyme: A special type of protein that can recognize and cut DNA at certain sequences of bases to help scientists separate out a specific gene.

Transgenic: A genetically engineered animal or plant that contains genes from another species.

Virus: A very simple microorganism, much smaller than bacteria, that enters and multiples within cells. Viruses often exchange or transfer their genetic material (DNA or RNA) to cells and can cause diseases such as chickenpox, hepatitis, measles, and mumps.

like colds, the virus is first changed so that it does not make the animal sick. Scientists insert the gene into the virus's genome. Then, when the virus infects the animal embryo (an animal in its earliest stages of development), it transfers the new gene into the animal's cells. The animal will then have the ability to produce the protein coded for by the new gene. Another delivery method is to inject the gene directly into the animal embryo's cells. This process is called microinjection.

To help treat disease, scientists can insert a human gene for a protein associated with the disease into an animal. The idea is to get the animal to produce the protein product of that gene in its milk or meat. Scientists also can change an animal's genes to mimic what would happen in human cells attacked by a certain disease. This model can help them understand how the disease works, and can allow them to test out potential drugs for treating the disease without endangering human lives.

Current Issues

Those who oppose genetic engineering say that it hasn't been tested well enough to ensure that it is safe. They worry that meat or milk from a genetically engineered animal might contain new proteins that could cause allergic reactions in certain people. There is also a concern that transgenic animals that escape or are released into the wild could disrupt or damage other species. For example, a fish that has been genetically engineered to grow larger than normal could disrupt the food supply, if is released into the ocean. Another concern is that a transgenic animal could mate and introduce its modified genes into the ecosystem with unknown results. An ecosystem is an interconnected community of animals, plants, and other organisms.

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[*See Also* **Vol. 2, Animal Cloning; Vol. 2, Genetic Engineering; Vol. 2, Genetically Modified Organisms; Vol. 2, Recombinant DNA technology; Vol. 2, Transgenic Animals.**]

Genetically Modified Organisms

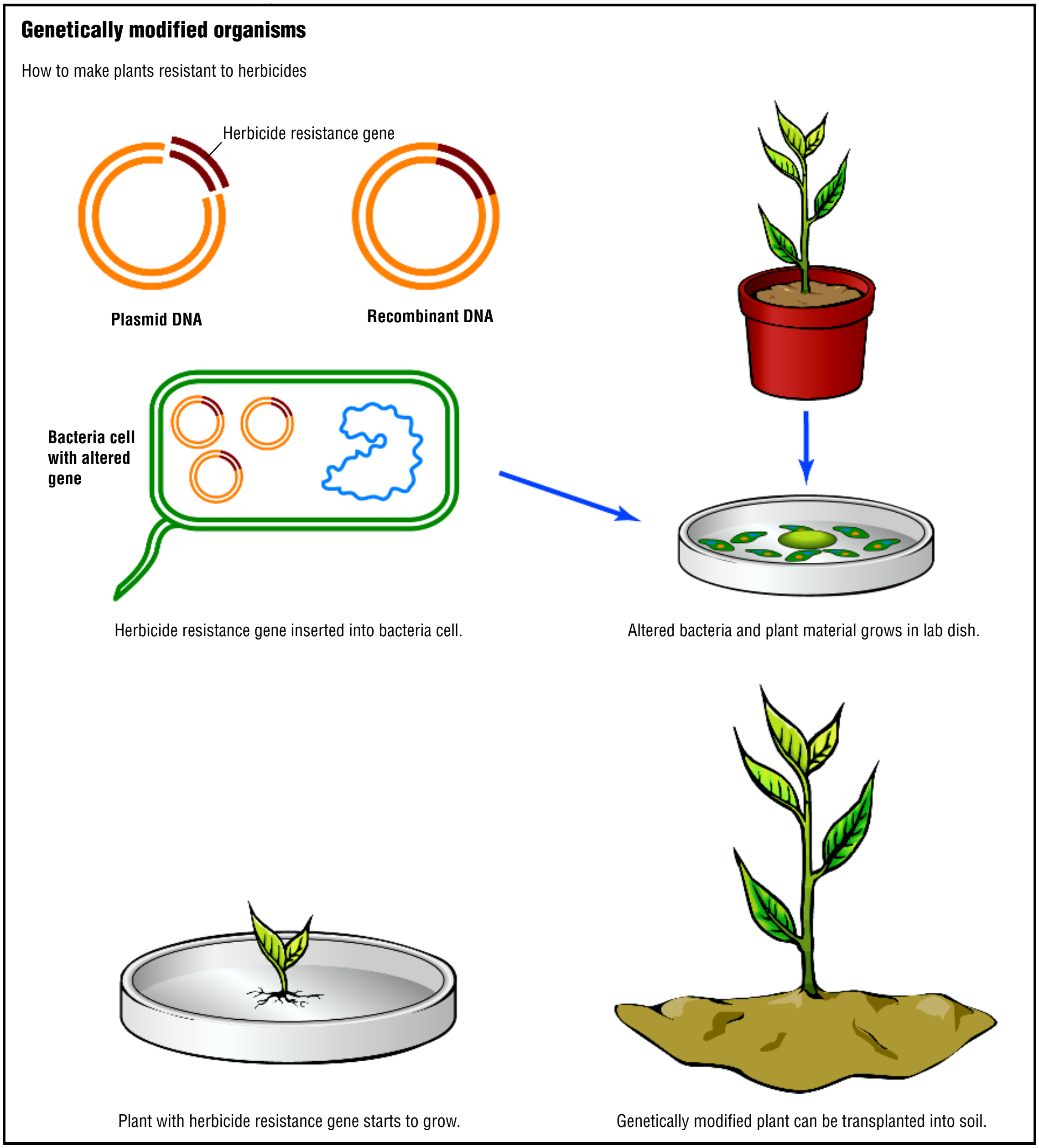
Description

Genetically modified organisms (GMOs) are living things whose DNA has been changed in the laboratory. Many kinds of genetically modified organisms have been created, including bacteria, viruses, yeasts, plants, and animals. Genetically modified organisms are also known as genetically engineered organisms or transgenic organisms.

Some GMOs have been made to study how heredity works and to test the tools of genetic engineering. One early GMO was a tobacco plant, made in 1986, that was given DNA from a firefly. The plant glowed in the dark. Glow-in-the-dark mice have also been grown.

Many genetically modified (GM) crop plants have been made, including corn, cotton, wheat, rice, and others. These plants tolerate more pesticides, make their own pesticides, grow in dry or salty places, or make medicines or extra vitamins. Some farmers, especially in the United States, Argentina, China, and a few other countries, buy GM seed hoping to make more money from their crops.

Some GMO animals have also been created. Salmon have been genetically modified to be sterile so that they can be released into streams and lakes but not breed with their wild relatives. Cows have been engineered to produce human growth hormone in their milk, for medical use. Goats have been engineered to produce spider silk in their milk; the goal is to harvest the silk (which is stronger, ounce for ounce, than steel) in large amounts and make useful new materials from it. GM sheep and pigs have been made that make human blood-clotting factor in their milk. This is the substance that stops bleeding from cuts. The factor can be purified and given to human hemophiliacs (people who lack the factor and so cannot easily stop bleeding).


Genetically modified organisms
How to make plants resistant to herbicides
Herbicide resistance gene
Plasmid DNA
Recombinant DNA
Bacteria cell with altered gene
Herbicide resistance gene inserted into bacteria cell.
Altered bacteria and plant material grows in lab dish.
Plant with herbicide resistance gene starts to grow.
Genetically modified plant can be transplanted into soil.

How genetic engineering is used to create plants that are resistant to herbicide (weedkiller). Plasmids are structures that carry genetic material in bacteria. When a foreign gene is introduced, the resulting DNA is called recombinant. *Illustration by GGS Inc.*

Genetically modified soybeans in the hands of a Romanian farmer. © *Bogdan Cristel/Reuters/Corbis.*

GMOs have also been created to use in treating medical problems. In the method called "gene therapy," for example, a GM virus is created that invades the cells of a person who is sick with some disorder of their DNA. The virus carries new DNA into the cells of the patient. Sometimes this new DNA cures the patient's disease. As of 2006, however, gene therapy was not yet safe enough to be used except in experiments.

Although nobody is known to have yet done such a thing, there is also a possibility that viruses or bacterial could be genetically engineered to act as weapons.

Scientific Foundations

DNA stands for deoxyribonucleic acid, the molecule that controls heredity and the making of proteins by cells. Heredity is the passing on of traits from parents to offspring; a protein is a kind of large molecule or group of atoms that is found in all living things. Almost all living cells contain one or more DNA molecules. Each DNA molecule is a long, twisted group of atoms that contains information written in a chemical code. Small groups of atoms

Genetically Modified People?

Human beings could, in theory, be genetically modified just like other creatures. Genetic modification could, for example, be used to help people who have genetic diseases—defects in their DNA that make them sick—to have healthy children. Some people also dream of engineering children to be blonde, tall, athletic, or smarter. However, it is not today scientifically possible to do this and it may never be. Also, most people feel that trying to create genetically superior people would be morally wrong. Genetic engineering of people is already illegal in some parts of the world. The Convention on Human Rights and Biomedicine of the Council of Europe (1997) forbids ''any modification in the genome of any descendants.'' (An organism's genome is the sum of its DNA.) As of 2006, there was no United States federal law banning the engineering of heritable genetic changes in human beings. Eleven states had laws banning research on human embryos that would probably apply to attempts to genetically engineer humans.

arranged along the DNA molecule spell out instructions for making proteins. Cells live, grow, and reproduce by making proteins according to the instructions in their DNA. Changing the DNA of a living thing changes how it lives, grows, and reproduces.

Development

The scientific understanding of genetics dates to 1865, when an Austrian named Gregor Mendel (1822–1884) published his studies of inheritance in pea plants. In the twentieth century, scientists extended Mendel's laws of heredity to evolution and selective breeding.

The nature of the DNA molecule was discovered in 1953 by James Watson (1928–), Francis Crick (1916–2004), and Maurice Wilkins (1916–2004). One by one, from the 1950s through the 1970s, chemical tools were discovered that allowed scientists to cut and duplicate pieces of DNA, bringing genetic engineering closer to reality. In 1977, it was discovered that a germ called *Agrobacterium tumefaciens* could be used to put genes (short sections of DNA) into the DNA of plant cells. Other methods were soon invented to change DNA. One of these is the gene gun, which literally shoots tiny bullets painted with DNA into cells.

By the late 1980s, many organisms had been genetically modified. In the 1990s, genetically modified plants—especially corn, cotton, canola, and soybeans—became important money-making crops in the United States and some other countries. In the 2000s, more GM crops were produced and research continued into GM animals.

Words to Know

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Gene gun: A device that shoots tiny metal bullets coated with DNA fragments into cells in order to alter their DNA permanently.

Current Issues

Many scientists believe that the creation of genetically modified organisms is a good thing. They believe that GMOs will not only make money for the companies that sell them, such as those that sell GM cotton, corn, soybean seed, but will help people in poor countries become healthier. Some scientists and many non-scientists disagree. They believe that GMOs will not help the poor and may damage human health or the environment.

All biologists agree that altered genes from GMOs, especially plants or bacteria, might mix with wild organisms and cause harm, but there is much disagreement over how big a danger this is. In many parts of the world, especially Europe and Japan, there is strong popular opposition to the idea of eating foods made from GM plants. In the United States, most packaged foods already contain some GM plant material.

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[*See Also* **Vol. 2, Corn, Genetically Engineered; Vol. 2, Cotton, Genetically Engineered; Vol. 2, Genetic Pollution; Vol. 1, Genetically Modified Foods; Vol. 2, Rice, Genetically Engineered; Vol. 2, Tomato, Genetically Engineered; Vol. 2, Transgenic Plants.**]

Herbicide-Tolerant Plants

Description

Herbicide-tolerant plants are crop plants that have been genetically engineered to resist the killing effects of a target herbicide. An herbicide is a chemical that kills plants, especially weeds. This enables the crops to survive the application of a herbicide that kills weeds and other unwanted plants.

There are two goals in using herbicide-tolerant plants. One goal is to increase the yield of plants per area of cultivated land, since weeds will not be competing with crop plants for the available space and nutrients. Secondly, the amount of herbicide that is applied during the growing season can be reduced, since fewer applications of herbicide will be needed. The targeted killing of unwanted plants using herbicides can also lessen the need to mechanically remove weeds.

Scientific Foundations

Almost all living cells contain molecules of DNA (deoxyribonucleic acid)—genetic information that is passed on to future cell generations. Genes are sections of DNA that contain recipes for the production of cell components called proteins. The genetic engineering of herbicide-tolerant plants involves the identification of a gene(s) that makes the herbicide less poisonous to the plant, usually by allowing the plant to break the herbicide down chemically. Alternatively, a gene can be identified that encodes (contains the recipe for) a protein to replace the plant protein that is usually the target of the herbicide. In contrast to the original protein, the replacement protein is not affected by the herbicide. In both methods, the target plant becomes resistant to the herbicide.

Row of apple trees with dead weeds beneath. The apple trees are able to withstand the application of herbicide, or weedkiller. © *Anthony Cooper; Ecoscene/Corbis.*

Once the herbicide-resistant gene has been identified, it can be introduced into a selected plant with the classic tools of biotechnology. Specialized chemicals called restriction enzymes allow the target gene to be cut out from the remainder of its DNA. Then the crop plant's genetic material can be cut in a similar way, and the new gene is used to replaced the cut section. The new herbicide-resistance gene can then become part of the crop plant's DNA set, where it can be duplicated as the cell reproduces itself.

Insert Here

One of the challenges in the genetic engineering of plant herbicide-resistance is that the inserted resistance gene tends to integrate randomly into the plant's DNA. Therefore, the gene may insert itself into one of the plant's genes, which would inactivate that gene. If the disrupted plant gene is vital for survival, the genetic engineering is a failure.

A newer strategy allows for more precise control over the insertion of the herbicide-resistance gene. Genes can be constructed that differ from the target plant gene only very slightly. When the constructed gene is inserted into a plant cell, its near-identity with the plant gene will cause the genes to align. By cutting the plant DNA with restriction enzymes, the subsequent repair process will substitute the inserted gene for the original gene. The herbicide-resistance will then be expressed without compromising any of the other plant genes. Although this technique is still under development, it holds great promise in the genetic engineering of plants.

Once the new gene is taken into the plant's DNA, it functions as it normally would and allows the plant to tolerate the herbicide.

Development

As of 2006, a number of crop plants had been engineered to be tolerant of several herbicides. The following are four examples:

Glyphosate, an herbicide marketed as Roundup® and several other brand names, inhibits the activity of a plant enzyme (a chemical that speeds reactions in living things) that is critical for the plant's survival. All green plants have this enzyme; thus, glyphosate is a broad-spectrum herbicide, meaning it kills many plant varieties. Varieties of corn, soybeans, cotton, canola, and sugar beets have been engineered to be glyphosate-resistant and will survive the application of this herbicide. The glyphosate-resistance gene is introduced to the crop plants using a soil bacterium (one-celled germ) called *Agrobacterium*; this bacterium routinely infects certain plants and so has been used as a way to deliver genes.

Glufosinate is another herbicide. A component of the herbicide called phosphinothricin is structurally similar to a chemical called glutamine. Normally, glutamine is required for the activity of a critical plant enzyme. When greater quantities of phosphinothricin are present, the compound can occupy the space within the enzyme that glutamine normally fits into, which blocks the enyzme's activity. Plants are engineered to be glufosinate-resistant by the addition of a gene encoding an enzyme that breaks down the herbicide. The

Words to Know

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Enzyme: A protein that helps control the rate or speed of chemical reactions in the cell.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Herbicide: A chemical substance used to kill weeds or undesirable plants.

Protein: Complex molecules that cells use to form most of the structures and control chemical reactions within a cell.

Restriction enzyme: A special type of protein that can recognize and cut DNA at certain sequences of bases to help scientists separate out a specific gene.

detoxifying enzyme enters the plant through a strain of *Streptomyces* bacteria. Corn, soybeans, cotton, canola, rice, and sugar beets have been engineered to be glufosinate resistant.

Cotton plants that are resistant to a herbicide called bromoxynil also have been created. This compound inhibits the photosynthesis process. However, when a gene from the bacterium *Klebsiella nitrilase* is introduced into the cotton plants, the engineered cotton plants are capable of breaking down the bromoxynil.

Finally, cotton and flax plants have been created that are capable of surviving exposure to a herbicide called sulfonylurea. The herbicide normally kills plants by blocking the activity of an enzyme that functions in the manufacture of several necessary plant chemicals. The herbicide-resistance enzyme was obtained from tobacco plants.

Current Issues

Public debate continues as to the wisdom of growing herbicide-tolerant crops. Those in favor of these crops point to the documented reduction in herbicide application and increased crop yields as evidence of their value. However, critics maintain that weeds can exchange genetic material with herbicide-resistant plants, and so can acquire the resistance themselves. They cite documented cases of this as an unwanted and dangerous side effect of growing herbicide-tolerant crop varieties. In addition, opponents see the increased control of food production by the private companies that produce these herbicide-tolerant plants as another concern.

Assessment of the safety of herbicide-tolerant plants continues. Such crops are rigorously evaluated by the U.S. government before approval is granted for their routine use. As new herbicide-tolerant crops are developed, this assessment will continue.

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[*See Also* **Vol. 2, Corn, Genetically Engineered; Vol. 2, Cotton, Genetically Engineered; Vol. 2, Salinity-Resistant Plants; Vol. 2, Tomato, Genetically Engineered; Vol. 2, Wheat, Genetically Engineered.**]

Hybrid Plants

Description

The term hybrid means a product formed by combining two different things. In nature, features of individual life forms come together in a single form to produce hybrid animals and plants. This is known as hybridization. Industries use such techniques to obtain desired features of distinct crop varieties to create hybrid plants. Hybrid plants often survive better than both types of plants from which they were taken, and they produce a better crop.

Some examples of hybrid plants are peppermint, a hybrid of water mint and spearmint; limequat, a hybrid of kumquat and lime; and triticale, a hybrid derived from wheat and rye.

Plants grow well only if they get soil, nutrition, and weather conditions best suited for them. A plant may grow well in one region but not in another. Guava, mango, and papaya, for example, are abundantly available in Southeast Asia, whereas their inability to survive in the United States makes them exotic. Developing hybrids can produce plant varieties that flourish in the soil and climate of a specific region. For example, mango plants can be hybridized to produce varieties capable of growing and tolerating soil and weather conditions found in the United States. Hybridization has its limitations, however, and not all attempts are successful.

Scientific Foundations

The typical process for raising hybrid plants involves, first, selecting the parent plants. Then, the female plant is pollinated with pollen from the male plant (which contains the male plant's genetic material). The seeds that the female plants produce from such cross-pollination contain genes from both the parents, thus

Stalks of wheat, rye, and triticale (center). Triticale is a hybrid of wheat and rye. © *Ted Streshinsky/Corbis.*

showing mixed traits of the two plants in a single crop. The plants grown from cross-pollinated seeds are referred to as F1 hybrids. In addition to showing desired traits of their parents, F1 plants are vigorous and more resistant to pests, parasites, and unfavorable weather conditions.

Hybridization does not always involve combining the genetic material of the two parents. Other techniques, such as grafting, are also used to develop hybrid plants. In grafting, the twigs of one plant are cut off and attached to the stem and root system of another plant. For instance, grafting the shoot system of a rose with strong flower formation on to another rose type with robust

The Next Generation of Hybrid Plants

An interesting phenomenon has been observed while studying development patterns of F2 plants (the next generation of plants grown from seeds of F1 hybrids). F2 plants are not as vigorous as their F1 parents and are more like the original plants from which F1 hybrids were derived. Consequently, F2 plants generally do not yield the same quality products as F1 plants. To obtain the desired characteristics, agriculturists need to use seeds derived from cross-pollinated plants only.

roots produces a hybrid that is commercially and visually more viable than the individual parent.

Development

Ever since humans started cultivating land, they have experimented with creating hybrids of different plant varieties to develop hardier, disease- and pest-resistant, high-yielding, and better-tasting crops with improved appearance. Several horticultural plants are hybrids that have been generated as a result of constant experimentation through hundreds of years.

Prior to genetics being established as a scientific field, farmers either used grafting or simply selected plants that showed desired traits and grew them in abundance. The selection process helped eliminate unwanted features and promote necessary qualities.

In the nineteenth century, Augustinian monk Gregor Mendel (1822–1884), presented his work on the laws of genetics in a paper published in 1866. Influenced and interested by his findings, farmers gradually started using their new found knowledge on genetics to grow hybrid plants showing desired characteristics.

Over the years, developments in hybridization have helped humankind in many ways. Hybridization has aided in addressing the hunger problem by enabling farmers to develop fast-maturing plants with shorter life cycles. Owing to better yielding hybrids of commonly used grains, vegetables, and fruits, farmers can now produce multiple crops in a single season. Weather-hardy hybrids have increased the feasibility of farming land when adverse climate conditions previously made it impossible to even sow seeds.

Hybridization has greatly sped up the evolutionary process, without which many types of crops in their current form may have taken hundreds of years to develop.

Words to Know

Cross-pollination: Transport of pollen from the flower of one plant to the flower of a different plant of the same species.

Genetics: The science of genes and heredity.

Global warming: A projected increase in Earth's surface temperature caused by an increase in the concentration of greenhouse gases, which absorb infrared energy emitted by Earth's surface, thereby slowing its rate of cooling.

Grafting: A method of propagation of woody plants whereby a shoot, known as a scion, is taken from one plant and inserted into a rootstock of another plant. Through grafting, large numbers of plants with the desired traits of the scion can be readily and quickly developed.

Current Issues

Creating hybrid plants is no longer bound by cross-pollination and other traditional methods. Hybridization in combination with selection has further helped develop varieties that uniformly produce the desired results. F1 hybrids are also back crossed with the dominant parent to retain the preferred features of that parent in the new plants. Cutting-edge technology has led to the development of laboratory culture (growing plants in laboratories) of new varieties.

Scientists today use tissue-culture techniques to harvest a single cell or a group of cells to create a functional plant, or a part of it. Suitable growth conditions are maintained in the laboratory, and tissues are grown in artificial materials to ensure best results. Genetic engineering (introducing genes from one organism into another cell or tissue) further allows scientists to transform the genetic makeup of a plant in order to obtain the desired trait.

Altering the genetic makeup of plants has many benefits, but it will be a long time before their true impact is known. Scientists are not sure about the long term effects of genetically hybridized plants. They have yet to study the effects of foods from such plants on living systems.

The idea of developing hybrid plants remains similar to what it was decades ago. In addition, studies are being conducted to develop plant varieties that can survive in increasing levels of carbon dioxide (a greenhouse gas) and ultraviolet rays from the Sun. This will help grow plants that can endure the modern-day threat of global warming.

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[*See Also* **Vol. 2, Breeding, Selective; Vol. 2, Plant Grafting.**]

Hydroponics

Description

Hydroponics is the growth of plants in a mixture of water and mineral nutrients, without the use of any type of soil. The two main features of hydroponics are the use of liquid solutions for plant growth and the support of plants with materials like gravel, which lets the nutrients go to the plant roots. Plants usually grow by using mineral nutrients from soil and non-mineral nutrients from air and water. With the use of hydroponics, plants do not get the nutrients normally taken from the soil. Instead, plant physiologists provide each plant with the correct amount of each nutrient needed to grow without soil.

Scientific Foundations

Plants need nutrients to grow and survive. Nutrients can be mineral or non-mineral. Non-mineral nutrients are carbon, hydrogen, and oxygen. They are found in air and water. Plants use energy from the Sun to change carbon dioxide (the gas that makes up the majority of what animals breathe out) and water into food (such as starches and sugars).

Mineral nutrients come from the soil. They dissolve in water and are absorbed into the plant's roots. Mineral nutrients are divided into macronutrients and micronutrients. Macronutrients, which are needed in large (macro) amounts, include nitrogen, phosphorus, and potassium (the primary nutrients); and calcium, magnesium, and sulfur (the secondary nutrients). Plants use large amounts of the primary nutrients so it may be difficult for plants to find enough of these nutrients. Plants find secondary nutrients easily. The micronutrients, which are needed in small (micro) amounts, include boron, chloride, copper, iron, manganese, molybdenum, and zinc.

Lettuce plants grown by hydroponics in Florida. © *Joseph Sohm, ChromoSohm Inc./Corbis.*

Development

Hydroponics originated in the seventeenth century when scientists discovered that some substances help plants grow. For instance, Belgian physicist Jan van Helmont (1577–1644) identified that plants use substances from water to grow. In 1627, English philosopher Francis Bacon's (1561–1626) book *Sylva Sylvarum* was published, which is the earliest known book on growing land-based plants without soil. Then, in the eighteenth century, solutions with mineral nutrients were first developed. In the 1860s, German botanists Julius von Sachs (1832–97) and Wilhelm Knop (1817–91) further modified these solutions. Over the next sixty years, additional laboratory experiments were performed to try and grow plants without soil.

Between the late 1920s and early 1930s, plant physiologists began to use their theoretical and experimental work for practical farming applications. American physician William Frederick Gericke, of the University of California, used his earlier work on plant nutrition to develop such crops as carrots, potatoes, radishes, and

Eurofresh Farms Produce Hydroponic Tomatoes

Eurofresh Farms was founded in 1990 by Dutch-American greenhouse owners Johan van den Berg and Wil van Heyningen. They chose Wilcox, Arizona, for their first greenhouses because of the location's sunny climate, water supply, and elevation. The two men introduced their first tomato in 1998, the tomatoes on the vine (TOV). Today, their two farms in Arizona sell over 100 million pounds (45 million kilograms) of tomatoes each year. Most importantly, they grow tomatoes every month of the year. Because of that fact, Eurofresh Farms is the leading year-round producer of greenhouse tomatoes in the United States. According to the American Culinary Institute, their TOV tomatoes were judged the 2006 Chef's Best^{TM} ''America's Best Tasting Tomatoes.''

various fruits and flowers without the use of soil. In 1937, Gericke created the word hydroponics from two Greek words: *hydro* (water) and *ponos* (labor). Although his way of performing hydroponics was considered too difficult for commercial farming, his work is still considered the foundation for all types of hydroponics.

In the late 1940s, American horticulturists Robert B. Withrow and Alice P. Withrow, of Purdue University, designed a practical hydroponic system. The U.S. and British militaries used hydroponic farms in World War II to feed their troops. They were used on islands where soil was not available and it was too expensive to fly in vegetables. Several commercial farms were established after the war, but most were not successful. Over the next two decades, hydroponic farms continued to develop in the United States and in such countries as England, France, Germany, Israel, Italy, Spain, Sweden, and the USSR (what is now Russia).

In the 1970s, plastics greatly improved the operations of hydroponic farms. Greenhouse covers, pipes, pumps, reservoir tanks, and other equipment were developed using plastics. With years of experience, better management techniques, and better technologies such as environmental control systems and specially formulated nutrient systems, hydroponic farms began to succeed in the late 1970s and continue to do so in the early twenty-first century.

Current Issues

Almost any plant can be grown with hydroponics under artificial or natural lighting and in almost any place in the world without worries of temperature changes, growing seasons, and climate changes. The environment for growing hydroponic plants is tightly

Words to Know

Mineral: A naturally occurring solid substance of nonbiological origin, having definite chemical composition and crystal structure.

Nutrient: A substance that provides nourishment.

pH: A measurement of the concentration of hydrogen ions in a solution of water. A neutral solution with equivalent amounts of hydrogen and hydroxyl ions has a pH of 7.0 at room temperature. Acidic solutions have a pH of less than 7.0 and basic (alkaline) solutions have a pH of more than 7.0.

Physiologist: A person who studies living plants.

controlled with respect to humidity (water content in the air), temperature, and pH levels (a chemical measure of acidity) so plants grow as best as possible. This technology is sometimes called Soil-less/Controlled Environment Agriculture (S/CEA). Some illegal activities, such as the growing of marijuana, utilize hydroponics. Such activities have given a bad name to hydroponics in the past and still somewhat hurt the industry.

Hydroponic farming tends to involve more expenses than traditional farming. As a result, few large-scale commercial hydroponic farms exist in the United States. The largest commercial facility in the United States is located in Wilcox, Arizona. The company has about 265 acres (107 hectares) used for hydroponic farming, which is about one-third of all the hydroponic acreage in the United States. Though expenses are greater, much less water is used—as little as one-twentieth the amount.

Hydroponic farming generally requires greater technical knowledge than traditional farming. It also requires more equipment. Maintenance of the equipment and materials is more time consuming and expensive. The failure rate of hydroponic plants is higher because any leak in the system can kill the plants that require very controlled conditions to grow.

Many false and misleading statements have been made in regard to hydroponics. For example, the claim that hydroponic farming produces greater crop yields than traditional farming is false. In addition, hydroponic plants do not necessarily taste better or are more nutritious than traditionally grown foods. Such claims have hurt the industry in the past, but have become a less serious problem.

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[*See Also* **Vol. 2, Agriculture; Vol. 2, Tomato, Genetically Engineered.**]

Plant Grafting

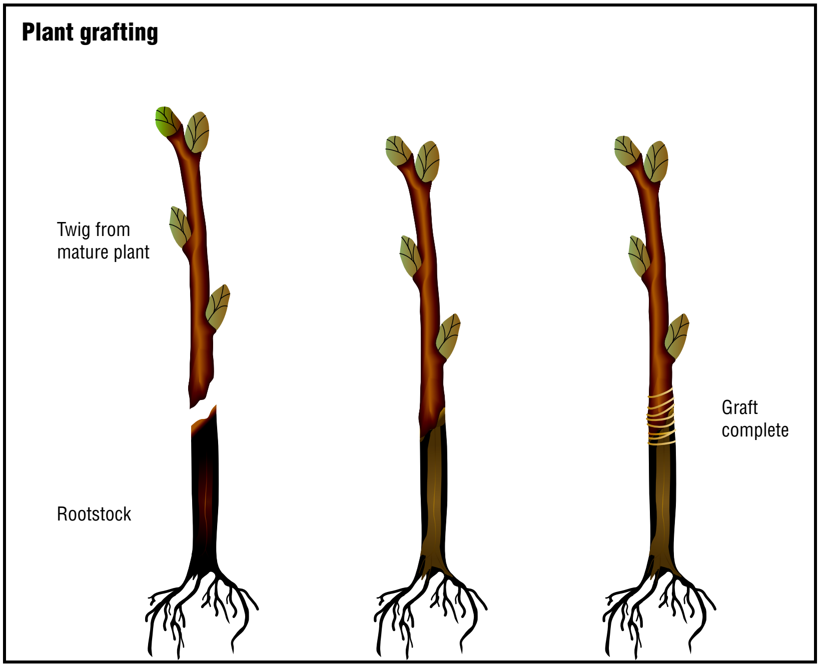
Description

Plant grafting is the method used to bring together the tissues of two existing plants so they grow as one. The new plant is not a new variety of plant because the characteristics of both plants remain the same. In general, only similar plants can be grafted successfully. Horticulturalists (scientists who specialize in growing flowers, trees, and shrubs) do most of the grafting of trees and shrubs in commercial growing facilities.

In grafting, a stem that contains one bud or several buds, called the scion, is cut. The scion is used for its flowers, fruits, leaves, or stems. The upper stem of a second plant is cut. The tissue of the scion is connected to the tissue of the stem of the second plant, which is called the stock. The stock is used for its root system. It may be a mature plant, such as a cherry tree, or it may be a root (often times from a seedling, or young plant). The two tissues then grow into each other. A new plant is made, with the scion forming the flowers, fruits, leaves, and stems, and the stock forming the roots.

The two plants are grafted together to bring the good qualities from both plants into the newly made plant. For example, the ability to fight diseases in one plant might be combined with another plant that grows tasty fruit to produce disease resistant fruit trees. Other reasons to perform plant grafting include producing a plant that is: smaller (called dwarfing), which is sometimes done to fruit trees so they can be picked easier; able to live in extremely cold weather; better suited to different soil; stronger and taller in the trunk, such as for ornamental trees and shrubs; able to produce fruit or flowers more quickly; and repaired so water and nutrients can reach all its branches.

How part of one plant can be grafted onto the rootstock of another. *Illustration by GGS Inc.*



Scientific Foundations

For a successful graft to occur, general (undifferentiated) cells that have the ability to develop into cells with special functions (differentiated cells) must grow on the surface where the plant is cut. These cells, which are called callus cells, grow from the cambium (the layer of tissue just under the bark of plants that carries water and nutrients) of the stock and the cambium of the scion. The callus cells combine to make a bridge between the stock and the scion. The cambium tissues then grow into vascular tissues. The connection between the cambium of the stock and the cambium of the scion allows water and nutrients to move back and forth in the vascular tissues, which produces a successful graft.

Development

Plant grafting was used by some of the world's oldest civilizations. When a good plant was found for its fruit, nuts, flowers, or other reason, the people tried to improve it. They learned the art of grafting most likely by seeing how plants in nature grafted onto other plants. These early grafting techniques most likely involved tying the two parts with the branches and roots of trees and shrubs. The two plants were held together for long periods until the bark crumbled and the tissues beneath the two plants made contact with each other.

New grafts on an old olive tree in Spain. © *Frank Lane Picture Agency/Corbis.*

It is known that people in China were grafting plants around 4,000 years ago. Articles on grafting were written in Greece beginning in the fourth century BCE. During the Roman Empire (between the first century BCE and the fourth century CE), grafting was commonly used to grow plants. About 2,000 years ago, people knew that problems could occur when grafting was performed. By the eighteenth century, scientific research was being done on grafting, and by the nineteenth century, over one hundred grafting techniques had been developed. Many of those same techniques are still being used in the twenty-first century.

Current Issues

Grafting was not always done with regard to the lasting health of the plant. As a result, grafting sometimes caused more problems than it prevented. In some cases, grafting hurt the general condition of plants; for example, it could make diseases more likely to occur.

Some groups have ethical and religious problems with any type of modification of plants (what is called plant propagation), including grafting. These groups state that any modification to the natural world is wrong. They do not grow or eat modified foods because it is against their moral views. However, plant propagation is the process of creating a new plant. Grafting is not usually considered a true type of plant propagation because it is only the transplanting of one part of a plant onto another plant. It does not create a new plant.

The Tree Circus of Axel Erlandson

In the early 1900s, Swedish-American Axel Erlandson (1884–1964) was a farmer in central California. After seeing natural grafting in his rows of bushes, Erlandson began to create designs on paper that he later turned to art as he pruned, grafted, and bent various trees. Erlandson bought land near the ocean and transplanted some of his most interesting designed plants with the hope of attracting tourists. He opened up The Tree Circus in 1947. Erlandson's arborsculptures (tree sculptures) can be seen at the Web site of American arborsculptor Richard Reames <http://www.arborsmith.com/treecircus.html>. Erlandson shaped trees for over forty years. Today, many of his unique trees have been transplanted to Bonfante Gardens in Gilroy, California.

Grafting allows new plants to be produced that are the same as the original plants. It allows more control of the size and shape of plants. Grafting also produces stronger plants. In addition, two or more varieties of fruit can be grown on the same tree.

When two plants are not suited to each other, the grafting can fail; this is called graft incompatibility. Weather conditions, such as wind or cold, might also damage the grafted plant.

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Words to Know

Cambium: A layer of actively dividing cells, from which tissues used for conducting water and nutrients are derived.

Horticulturalist: A person whose job it is to grow plants in a garden or greenhouse.

Plant propagation: The process of spreading plants either artificially or naturally.

Scion: The upper or transferred component of a grafted plant.

Stock: The lower part of a graft, which generally turns into the root system of the resulting plant (also called a rootstock or understock).

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[*See Also* **Vol. 2, Hybrid Plants.**]

Pseudoscience and Biotechnology

Description

Pseudoscience is any set of beliefs that tries to sound scientific but is not science. Lysenkoism was a kind of pseudoscience that arose in the Soviet Union in the 1930s. It rejected the modern science of genetics in favor of non-scientific beliefs based on the theories of Jean-Baptist Lamarck (1744–1829). Lamarck had thought that changes to creatures caused by things that happened to it during life could be passed on to its offspring. For instance, an antelope might stretch its neck to reach leaves high up on trees; according to Lamarck, the antelope's offspring would have slightly longer necks because their parent's necks were stretched.

Lamarck was a real scientist in his day. Lysenko was not a real scientist, but he was favored by Soviet dictator Joseph Stalin. At Lysenko's urging, Stalin saw to it that scientists who disagreed with Lysenko—and all real biologists did—were fired from their jobs, arrested, and often killed. It was not until the 1960s, when Lysenko's ideas were finally given up, that Soviet biology began to recover.

Scientific Foundations

In the nineteenth century, Charles Darwin (1809–1822) discovered how change happens in evolution. Changes that can be passed on to offspring happen randomly in every generation, Darwin realized; changes that help animals survive and have more offspring are preserved, while those that do harm are weeded out. He called this process natural selection. He also believed that Lamarck's process, which was called the inheritance of acquired characters, could play a part in evolution. Today, scientists know that although some

Trofim Lysenko in a field in the present state of Ukraine. © *Hulton-Deutsch Collection/ CORBIS.*

acquired characters can be inherited for a few generations under some conditions, it is not a major force in evolution.

Lysenko's Lamarckian ideas were completely wrong. For example, Lysenko believed that grain that had been pre-soaked in ice water would grow better in cold climates. He did not do proper experiments and did not allow other scientists to challenge his ideas. His beliefs were pseudoscience.

Development

Trofim Lysenko's fame began in 1927, when he claimed to have discovered a way of making winter grain crops grow better by prechilling the grain. He called this method vernalization. The government newspaper *Pravda* (Russian for "truth") gave a glowing report of his supposed discovery. He was given help to start a journal to spread his beliefs about vernalization. In 1935, he announced a new theory of heredity that rejected genes (hereditary units in cells that determine an organism's characteristics) entirely. He denounced genetics as evil. In 1940, scientists who opposed Lysenko were began to be arrested. Soviet biology was crippled for at least 20 years afterward.

Now You See It, Now You Don't, Now You Do

The federal government gives grants of money to some college students in the physical sciences. These grants are called National Science and Mathematics Access to Retain Talent (SMART) Grants. Every year, the government prints a list of what majors (fields of study) can get grants. Talk of Lysenkoism surfaced again in 2006 when it was reported that the major ''evolutionary biology'' had disappeared from the latest list. In its place was a blank line. Since political conservatives often oppose evolutionary biology and the Bush administration is conservative, the government was immediately accused of a new, Lysenkoist attack on science. A few days later, however, the Department of Education announced that the blank line was a mistake, and that evolutionary biology was still eligible for SMART grants.

Current Issues

The word "Lysenkoism" is used today as an insult when somebody wants to accuse somebody else of twisting science to fit politics. For example, in 1983 biologist Davis Bernard published an article titled "Neo-Lysenkoism, IQ, and the Press," accusing fellow scientist Stephen Jay Gould of arguing against the IQ theory of intelligence for political reasons. (Gould's attack on the IQ theory has been both defended and attacked by other scientists.) In 2006, author Jonathan Wells accused modern evolutionary biologists of Lysenkoism. "Lysenkoism is now rearing its ugly head in the U.S.," Wells wrote, "as Darwinists use their government positions to destroy the careers of their critics." The critics Wells refers to are believers in creationism and intelligent design, two religiously-motivated, anti-evolutionary schools of nonscientific thought. All but a tiny handful of scientists agree that evolution is true and that creationism and intelligent design are pseudoscience. Critics of creationism and intelligent design have also compared them to Lysenkoism.

In 2004, the Union of Concerned Scientists (a private group) published a report claiming that the administration of President George W. Bush was twisting science to agree with politics. The report, which had been signed by twenty winners of the Nobel Prize, the highest honor in science, said that "there is a well-established pattern of suppression and distortion of scientific findings by high-ranking Bush administration political appointees across numerous federal agencies." The report also spoke of "a wide-ranging effort to manipulate the government's scientific advisory system to prevent

Words to Know

Lamarckism: The belief that acquired characteristics can be inherited, that is, that changes to an organism that happen during its life can be passed on to offspring.

Lysenkoism: A type of pseudoscience that arose in the Soviet Union in the 1930s and destroyed Soviet biology for decades. Lysenkoists denounced modern evolutionary biology and genetics.

Pseudoscience: Any system of beliefs that claims to be scientific but does not follow the scientific method by which scientific knowledge is produced.

the appearance of advice that might run counter to the administration's political agenda." In particular, the scientists claimed that the U.S. government was twisting or silencing science to cover up the reality of global climate change. Although the report did not mention Lysenkoism, many political commentators were quick to make the connection. The Bush administration defended itself against the charges, claiming that the scientists were biased against the administration.

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[*See Also* **Vol. 1, Bioethics.**]

Recombinant DNA Technology

Description

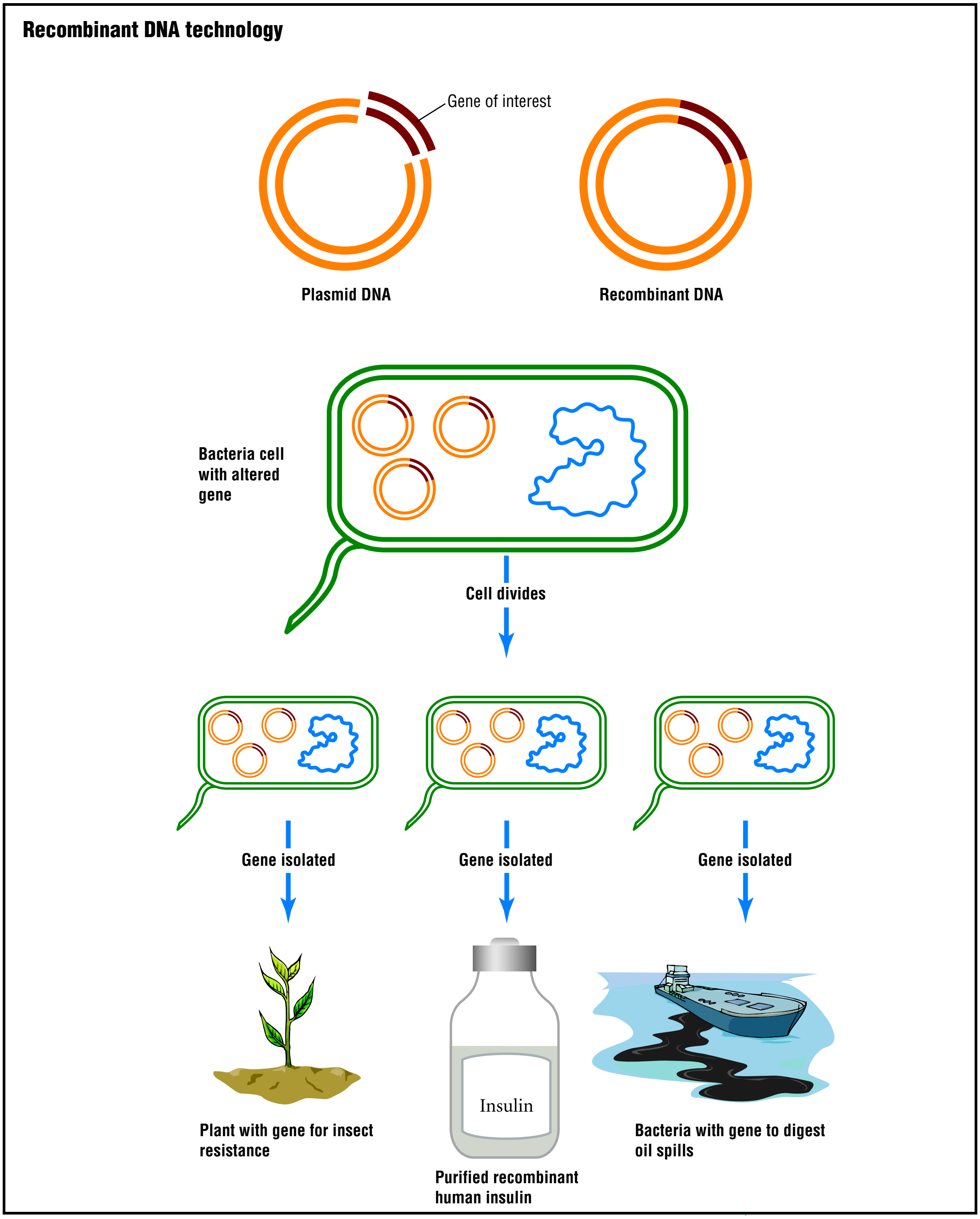
Recombinant deoxyribonucleic acid (DNA) is a type of DNA created for a special purpose by combining portions of the DNA from two or more different organisms. The term recombinant was given to the recombined DNA that is the result of this genetic engineering.

DNA is a molecule of hereditary information found in nearly every living cell. Genes are sections of DNA that contain a recipe, or code, for the production of specific proteins, substances used to control cell functions. Recombinant DNA brings together pieces of DNA that normally would not be found together in nature. For example, a gene found in some fish that carries the instructions for a protein that helps the fish to survive at cold temperatures can be transferred into some plants grown as food crops. As a result of the gene transfer, the plants (also called recombinant plants because they carry recombinant DNA) become much hardier and able to withstand colder temperatures.

Another important example involves the transfer of the gene carrying the instructions for the production of the hormone insulin (a chemical that helps regulate blood sugars) into the bacterium *Escherichia coli* (also called *E. coli*). Bacteria containing the new genes (recombinant bacteria) can then be grown in the laboratory on special dishes with food medium (culture dishes). These dishes become covered with billions of bacteria that produce insulin. Most of the insulin used by diabetics (people with disorders involving blood sugar balance) is now produced this way.

Scientific Foundations

All recombinant technology is based on the DNA molecule. DNA is commonly called the building block of life. It directs how an organism functions, develops, and looks.


Recombinant DNA technology
Gene of interest
Plasmid DNA
Recombinant DNA
Bacteria cell with altered gene
Cell divides
Gene isolated
Gene isolated
Gene isolated
Insulin
Plant with gene for insect resistance
Purified recombinant human insulin
Bacteria with gene to digest oil spills

How recombinant DNA is used to create a variety of end products, from genetically engineered plants to drugs to specialized bacteria. *Illustration by GGS Inc.*

Each molecule of DNA has two strands wound together to form a helix (a twisted ladder shape). Each strand is composed of individual nucleotides (a chemical building block of DNA) linked together. There are four different nucleotides: adenine, thymine, guanine, and cytosine. When the nucleotide strands come together to form the double-stranded DNA molecule, the nucleotides can only match up in certain pairs—adenine with thymine and guanine with cytosine. There are many reasons why they can only combined in this way; some of these reasons are related to the shape of the molecules. These special pairs are called complementary nucleotides. It is the order of the nucleotides that determines DNA's instructions.

In recombinant DNA technology, the proper pairing of the complementary nucleotides is helped by gently heating the individual strands of DNA. When not wound together in the DNA ladder-like helix, the separated strands are open to the action of a series of specialized enzymes (chemical compounds that speed up the rate of some chemical reactions) that are known as restriction enzymes. Each enzyme recognizes a specific sequence of nucleotides and can chemically cut the DNA at that sequence.

Recombinant DNA technology and procedures are important to many biotechnology applications.

Development

The process for creating recombinant DNA was started by two American biochemists, Herbert Boyer (1936–) and Stanley Cohen (1935–). In 1973, they published a paper describing this new technology. Other scientists immediately recognized how important this discovery was. Indeed, before the end of the 1970s, companies started using recombinant DNA to make chemicals and medicines.

The recombinant DNA technology devised by Cohen and Boyer relies on restriction enzymes that cut DNA into very specific smaller pieces. Each particular enzyme recognizes a sequence of nucleotides in a genome (the set of genes) and cuts the DNA at that location. The result is the isolation of the desired stretches of DNA that contain specific target gene. Using a technique called gel electrophoresis (a laboratory procedure that separates molecules of different sizes and electrical charges) the gene of interest is then further isolated from others (a process called purification).

Once the desired gene has been isolated from other genes, it can then be inserted into a circular piece of DNA called a plasmid from

Recombinant DNA and Asilomar

In 1974, less than a year after the publication of Cohen's and Boyer's paper on recombinant DNA, American scientists placed a moratorium on (suspended or stopped) recombinant technology until a discussion about its use could occur. Leading scientists met at Asilomar, California, to consider whether the moratorium should be lifted and, if so, how recombinant DNA research should be controlled and the safety of the public protected. The guidelines for the technology that emerged from the Asilomar conference eventually formed the basis of regulations enacted by the U.S. National Institutes of Health and similar bodies worldwide.

One issue that conference delegates did not consider was recombinant plants. Today, debate concerning the benefits and pitfalls of recombinant plants appears almost daily in news reports.

the target organism. Something like a ring being cut to make it a new size, the plasmid itself is opened by cutting at certain locations with restriction enzymes. A strand of DNA bearing the desired gene then attaches to the opened ends of the plasmid, which can then be stitched back together. Inside the target or host organism, the plasmid makes copies of itself. When these new copies are made, so also are the newly introduced genes. The DNA of the plasmids can then be used to manufacture desired proteins that cells use to build cell structures and control chemical reactions. Cohen and Boyer were successful in transferring recombinant plasmid DNA to another organism that then made the desired gene product.

This technology was subsequently adapted to transfer many different genes to a wide variety of host (target recipient) organisms. This technique continues to be used, as new genes and potential target organisms are identified. In addition, the various experimental laboratory techniques used in the recombinant DNA process, such as gel electrophoresis, have themselves become important research and commercial tools.

Current Issues

Just as the significance of the many potential uses of recombinant DNA technology was immediately recognized, so was the potential for misuse of this technology. Critics of recombinant DNA technology caution against the mixing of DNA from unrelated species. Briefly, the argument is that because recombinant DNA could make possible genetic combinations that would not otherwise occur, and

Words to Know

Biotechnology: Any technique that uses parts of living organisms to create or modify products, plants, animals, or microorganisms for specific uses.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Gel electrophoresis: A laboratory test that separates molecules based on their size, shape, or electrical charge.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Nucleotide: Molecular unit that is the building block of DNA.

Plasmid: A circular piece of DNA that exists outside of the bacterial chromosome and copies itself independently. Scientists often use bacterial plasmids in genetic engineering to carry genes into other organisms.

Recombinant DNA: DNA that is cut using specific enzymes so that a gene or DNA sequence can be inserted.

Restriction enzyme: A special type of protein that can recognize and cut DNA at certain sequences of bases to help scientists separate out a specific gene.

that have not been tested by the long, slow process of evolution, the recombinant organisms might be able to out-compete natural species with undesirable and unforeseen consequences.

Recently, scientists have discovered that genetic recombination, even between widely dissimilar species, is more common in nature than previously thought. This discovery has reassured some critics of recombinant DNA technology. However, the specter of bioterrorism—employing devastatingly infectious microorganisms created with recombinant techniques—has kept alive the most serious concerns surrounding recombinant DNA.

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[*See Also* **Vol. 1, Designer Genes; Vol. 1, Enzyme Replacement Therapy; Vol. 2, Genetically Modified Organisms; Vol. 1, Insulin, Recombinant Human.**]

Rice, Genetically Engineered

Description

About half the people on Earth depend on rice as their basic food. Rice is a cereal grain, which means it is a tall grass whose seeds are used for food. Corn, wheat, oats, and barley are also cereal grains. Genetically engineered rice, also called transgenic rice, is rice whose DNA (deoxyribonucleic acid, its genetic information) has been changed in the laboratory.

As of 2006, there were no varieties of genetically engineered rice on the market, but at least six kinds were under development. The first type is herbicide-resistant rice. Herbicides, or weed killers, are used by farmers to kill unwanted plants. If a field growing an herbicide-resistant crop variety is sprayed with weed killer, only the weeds will die, not the crop. One variety of genetically engineered rice is immune to the herbicide glyphosate. Glyphosate, the most popular herbicide in the world, is usually sold under the brand name Roundup®. Crops that are immune to glyphosate are called Roundup Ready®. Another kind of herbicide-resistant rice is immune to the herbicide ammonium glufosinate, and is sold under the brand name LibertyLink® Rice.

A second kind of genetically engineered rice is pest-resistant rice. One kind of pest-resistant rice is Bt rice. Bt is short for *Bacillus thuringiensis*, the scientific name for a kind of bacterium (very small, usually one-celled, organism) that lives in soil. Bt bacteria make a chemical that is poisonous to moths and butterflies in an early stage of life. Bt corn, cotton, and rice are genetically engineered varieties of those crops that have been given the gene (piece of DNA) that Bt bacteria use to produce this chemical. When insects try to eat the plant, they are killed or sickened by the chemical.

A biotechnologist with Golden Rice plants at a laboratory in the Phillipines. *AP/Wide World Photos.*

A third kind of genetically engineered rice is resistant to some bacteria and viruses that cause disease in plants. One genetically engineered variety of rice has a gene taken from wild rice, the Xa21 gene. The Xa21 gene makes the rice immune to some strains of the bacterium *Xanthomonas oryzae*. Other kinds of rice that will be resistant to certain viruses also are being developed.

A fourth kind of genetically engineered rice is called "biofortified." To fortify a food is to add a nutrient to it, such as a vitamin. To biofortify a food plant is to genetically engineer the plant so that it is more nutritious to eat. A type of rice called Golden Rice has been genetically engineered to add vitamin A. Its makers believe that it will help people in poor countries, where lack of vitamin A is a common cause of blindness.

Anti-Pest Baby Food

In 2005, the *New York Times* newspaper reported that in parts of China genetically engineered rice had been for sale for at least two years. Selling genetically engineered rice is illegal in China because the government has not yet approved any of the varieties that have been made. The illegal rice was labeled ''anti-pest rice'' (not genetically engineered rice) and seems to have come from a nearby university that studies the genetic engineering of rice. Hundreds of tons of the rice had already been grown, sold, and eaten, according to the environmental group Greenpeace, which opposes genetic engineering and discovered the illegal rice. In March 2006, Greenpeace also showed that that the illegal rice was even being used to make Heinz brand baby food sold in China.

Fifth, some rice varieties are being genetically engineered to survive dry weather, salty water, or too much water. Finally, some rice has been genetically engineered to produce drugs. A U.S. company, Ventria Bioscience, for example, has created a kind of rice that makes an anti-diarrhea drug. The rice is meant to be ground up and fed to children with diarrhea, which in poor countries is a life-threatening disorder that kills many thousands of children every year.

As of 2006, genetically engineered rice was not yet legally grown for food anywhere in the world. LibertyLink rice had been approved for farming in the United States, but no farmers were growing it yet because they were worried that they would not be able to sell their crop to Japan or Europe, where popular feeling against genetically engineered foods is strong.

Scientific Foundations

All living things use the molecule called DNA to pass traits on to the next generation. Almost every cell contains all the DNA that a plant or animal needs to make offspring. DNA, which is shaped like a long, twisted ladder, also tells each cell how to make all the materials that it needs to live. In nature, changes in DNA happen slowly over time. Genetic engineers, however, can change a plant's or animal's DNA in a single generation. They do this by adding new genes to an organism's DNA. Genes can be added to a plant's DNA using a device called a "gene gun," a machine that shoots tiny metal bullets coated with copies of the gene through a cell. Some of the new DNA stays in the cell and gets added to the cell's DNA.

Words to Know

Biofortify: To genetically engineer a crop plant so that it produces more of a certain nutrient, such as iron or a vitamin.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Golden Rice: A kind of genetically engineered rice that is yellow because it contains substances that the body can use to make vitamin A.

Herbicide: A chemical substance used to kill weeds or undesirable plants.

Transgenic: A genetically engineered animal or plant that contains genes from another species.

Vitamin A: A substance found in food (or made by the body from substances found in food) that is needed for metabolism (a body's chemical reactions). Lack of vitamin A can cause blindness.

Development

The structure of DNA was discovered by American biologist James Watson (1928–) and English biologist Francis Crick (1916–2004) in 1953. Chemicals called restriction enzymes were discovered in 1970, which allowed biologists to cut DNA molecules at chosen spots. This made it possible to separate single genes from larger DNA molecules. DNA from a mouse was moved into a bacterium in 1973, creating the world's first genetically engineered organism. In 1986, genetically engineered tobacco was the first transgenic crop to be tested in open fields. Genetically engineered tomatoes, corn, cotton, and other crops were first grown in the 1990s. Rice has been slower to arrive, but several varieties were ready for field testing in the early 2000s.

Current Issues

The same arguments are made for and against genetically engineered rice as with genetically engineered corn, cotton, and other crops. Many scientists, though not all, believe that genetically engineered crops are safe. Those who favor genetically engineered crops say that they are safe to eat, will help feed a hungry world, and will allow farmers to make more money while using fewer chemicals. Those who oppose the new crops say that poverty, not lack of food, is the root cause of hunger. They believe that there is a danger that genes from genetically engineered rice and corn will mix with the thousands of local varieties that have been developed by small farmers over many centuries. They also warn that traits like resistance to herbicides might jump to weeds or force weeds also to evolve resistance, creating what some call “superweeds” and forcing farmers to use more herbicide than ever.

In the case of rice, there is a particularly bitter argument over Golden Rice. This is the type of genetically engineered rice that contains substances that the human body uses to make vitamin A. Those who oppose it say that it contains too little vitamin A to be valuable. According to the environmental group Greenpeace, a person would have to eat almost 20 pounds (9 kilograms) of cooked Golden Rice every day to get enough vitamin A. Greenpeace and others who oppose Golden Rice say that the real causes of lack of vitamin A are poverty and a poor diet with little variety of foods. Supporters of Golden Rice claim that its use could prevent tens of thousands of poor children from blindness.

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[*See Also* **Vol. 2, Alfalfa, Genetically Engineered; Vol. 2, Cotton, Genetically Engineered; Vol. 2, Corn, Genetically Engineered; Vol. 3, Plant-Made Pharmaceuticals; Vol. 2, Tomato, Genetically Engineered; Vol. 2, Transgenic Plants; Vol. 2, Wheat, Genetically Engineered.**]

Salinity-Resistant Plants

Description

Salinity-resistant plants are plants—usually those used on farms—that are able to survive and even thrive in conditions where elevated concentrations of minerals, in particular sodium, are present.

While plant varieties that can survive in soils with higher salt levels can be produced by the classical plant breeding techniques, the invention of genetic engineering techniques has made it possible to take salinity-resistance traits from one organism and introduce them into a target plant species.

The United States Department of Agriculture estimates that every year, about 25 million acres (10 millions hectares) of farmland worldwide are lost because the soil becomes too salty for plants to grow. The salty soil is mostly due to irrigation, when the water used to nourish the growing plants also deposits the minute quantities of salt it contains. Over time, especially during periods of drought (an extended period of low rainfall), the deposited salt accumulates to the point where it makes the soil unable to support the growth of most agricultural plants.

Scientific Foundations

While salt (sodium) is vital for the biochemical processes that take place in plant cells and for maintaining the proper structure of the plant cell membrane, too much sodium can be devastating. Elevated sodium can cause a plant cell to attempt to balance the sodium concentrations outside the cell. This often involves the flow of water into the cell, which causes the cell to burst.

Almost all living cells contain molecules of DNA (deoxyribonucleic acid)—genetic information that is passed on to future cell generations. Genes are sections of DNA that contain recipes for the production of

Apple of Sodom plant on shore of Dead Sea. The plant is resistant to salty (saline) soils. If scientists can identify a gene for salinity resistance, it can be transferred to other plants using genetic engineering techniques. © *Richard T. Nowitz/Corbis.*

cell components called proteins. The genetic engineering of plants to produce characteristics such as salinity-resistance involves the creation of a plant that contains a gene taken from another organism. Essentially, the desired gene (for salinity-resistance, in this case) is cut out of one set of DNA and pasted into the target plant's DNA. The genetically

Plant Biotechnology Is Centuries Old

Plant breeding dates back approximately 10,000 years. Indeed, most of today's major food crops were created by the deliberate breeding of plant varieties. While it was not known at the time, conventional breeding process, such as the grafting of one plant part onto another plant, involve the exchange of genetic material between the grafted cells and the cells of the recipient plant.

By the first decade of the twentieth century, plant scientists had recognized the relationship between plant breeding and the inheritance of characteristics in succeeding plant generations. With the advent of recombinant DNA technology in 1973, the ability to tailor the genetic makeup of plants became possible. Conventional plant breeding has subsequently given way to the sophisticated techniques of genetic manipulation.

engineered plant then uses (expresses) the inserted gene to produce the protein product. It is this product that produces the salinity-resistance.

In addition to the actual gene, the transgenic plant (as the target species is known after the introduction of the new gene) needs also to contain a DNA sequence that controls the reading (transcription) of the gene—the sequence is known as a promoter—and a sequence that stops the transcription process (a termination sequence). Inclusion of these sequences allows the expression of the inserted gene to be finely controlled.

It is also necessary to have some means of tracing the inserted gene in the recipient plants. As in other applications of genetic engineering, this is accomplished by incorporating a "marker" gene that codes for resistance to a particular antibiotic. Thus, plants that die in the presence of the antibiotic will not have incorporated the transferred gene, while plants that survive antibiotic exposure will have successfully incorporated the new gene and expressed the encoded proteins.

Salinity-resistant genes can be introduced to the target plants using *Agrobacterium tumefaciens* or *Agrobacterium rhizogenes*—two bacteria (one-celled germs) that commonly infect plants. The bacteria act as vectors (vehicles that move the new genes into the plant cells). Viruses, such as the cauliflower mosaic virus, that infect plants also are sometimes used as vectors.

Development

Several varieties of salinity-resistant, transgenic plants have been created. Rice, a crop that is very dependent on the presence of ample

Words to Know

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Salinity: The amount of dissolved salts in water.

Transgenic: A genetically engineered animal or plant that contains genes from another species.

Vector: A vehicle used to deliver foreign genes into another organism's DNA. Viruses are the most commonly used vectors.

moisture, is one example. Increasingly, areas of the globe that produce large rice crops are experiencing drought, which can increase the salt concentration in the water. Field tests have established that a transgenic rice variety that carries a bacterial gene coding for a substance called choline oxidase grows better in higher salinity conditions.

Transgenic, salt-tolerant tomato plants also have been grown, but are still in the research and development phase. Scientists at the University of California at Davis have created a tomato that not only allows farmers to grow them in salty soils, but in addition, the tomato plant draws salt out of the soil and into its leaves, making the soil suitable again for growing certain other crops.

Current Issues

Research continues to further develop transgenic salinity-resistant plants so that they become a reliable and safe source of food. In addition, research is needed to conclusively establish whether or not transgenic plants pose a threat to wild plant populations. Finally, since much of the research on salinity-resistant plants is being done by private companies, some people are concerned about what will happen if food production falls largely under the control of large corporations.

The need for salinity-resistant plants is increasing as more areas of the world experience drought. The lack of water during a drought acts to increase the concentration of sodium in the water that is available. Without salinity-resistant plants, an adequate food supply may become even more difficult to achieve.

■ ■ ■

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[*See Also* **Vol. 2, Drought-Resistant Crops; Vol. 2, Genetic Engineering; Vol. 2, Transgenic Plants.**]

Sentinel Plants

Description

Sentinel plants, which are sometimes also called smart plants, are bioengineered (genetically engineered) plants that are specifically designed by humans to respond more noticeably or more quickly if harmful biological or chemical agents (materials) come close to them. A common reaction of these plants to a change in their environment is to change colors. Although sentinel plants have not yet been used in real-life situations, they have the potential to act as warning systems in dangerous situations such as bioterrorism.

Because plants do not move, they have evolved over time to become sensitive to their local environments. They often change color or shape, or give off substances into the air, when something unusual happens to their environment. For example, plants respond by simply changing colors when they are not given enough water. Because of these characteristics, scientists have found that plants can be designed to become aware of dangerous agents added to the environment and then act in known ways. In one study, scientists have injected a fluorescent substance into plants in order to cause them to glow.

Scientific Foundations

DNA (deoxyribonucleic acid) is a molecule found in nearly every living cell. DNA holds hereditary information, and sections of DNA are called genes. To increase a plant's response to its environment, scientists must first understand how genes act in plants. In scientific studies, a flowering plant from the mustard plant family, *Arabidopsis thaliana* (or mouse-ear cress), is being

Preventing Citrus Canker with Sentinel-Like Plants

While scientists develop advanced techniques to create sentinel plants, more elementary uses are being put into practice with plants that already behave in ways that make them able to be used as sentinels. For example, the Animal and Plant Health Inspection Service (APHIS) within the U.S. Department of Agriculture (USDA) has found a simple way to detect citrus canker when it first appears in citrus crops such as orange, lemon, and lime trees. Citrus canker is a disease that causes sores on citrus trees. The sores do not harm humans but do harm the quality of fruit. Early action against citrus canker can stop the spread of the disease and save millions of dollars in the citrus industry. To find citrus canker, researchers regularly inspect trees of a certain type, used as sentinels, within a grove of fruit trees. If any of these trees show infection, the researchers know that the rest of the grove probably has citrus canker. In this way, the entire grove does not have to be inspected, only particular trees that are evenly spaced throughout the grove.

researched as a sentinel plant. Scientists use this plant as a model for sentinel plants because it has a simple structure, it is found commonly around the world, and its entire gene sequence has been worked out.

Arabidopsis, along with other plants, notices and responds to things through cellular proteins called receptor-like kinases (RLKs). (Proteins are substances in cells that control their functions.) *Arabidopsis* has more than six hundred RLKs, but scientists have identified only about ten of these proteins. Unfortunately, it is not known what these proteins sense and what their responses are. To learn more about this plant, scientists use technology based on recombinant DNA—placing one piece of DNA into another organism's DNA set. They combine the sensing part (the receptor) of these proteins to the response part (the kinase) of another protein. This combination affects the plant's genes, which sometimes produces a response. With this research, scientists hope to develop specific plants that respond to environmental stimuli in specific ways.

Development

The technology behind using sentinel plants as an early-warning device is very young. In the early 2000s, researchers from Pennsylvania State University and Colorado State University began observing and measuring genetically engineered plants to see how they react to harmful materials located nearby.

Words to Know

Bioengineered: The process of using engineering to solve medical problems.

Deoxyribonucleic acid (DNA): DNA—The double-helix shaped molecule that serves as the carrier of genetic information for humans and most organisms.

Organism: Any living thing.

Pathogen: A disease causing agent, such as a bacteria, virus, fungus, etc.

Toxin: A poison that is produced by a living organism.

The researchers are using a three-year, $3.5-million grant from the Defense Advanced Research Projects Agency (DARPA). Two of the researchers are American chemical ecologist Jack Schultz, a professor of entomology at Penn State's College of Agricultural Sciences, and American biologist Ramesh Raina, an assistant professor of biology in Penn State's Eberly College of Science. Schultz and Raina, along with other associates, are learning the basics of the science of using sentinel plants to perform anti-terrorism tasks and other beneficial pursuits. Officials within DARPA, under the leadership of the U.S. Department of Defense (DoD), hope to develop sentinel plants by that can test for explosives in real-world situations by the last half of this century.

Current Issues

Although the technology used for sentinel plants is in a very early stage, if successful, common plants found around the world could be used as sentinel plants to quickly identify and respond to biological and chemical agents. Plants are good candidates to use for detecting harmful agents because they can be grown easily in any place where detection is needed, such as around government buildings, shopping malls, office buildings, bridges, airports, and power plants. The use of sentinel plants is also an inexpensive way to defend against terrorism.

Scientists hope that someday soon sentinel plants will sense and warn of the presence of dangerous chemicals or pathogens (disease-causing germs) such as anthrax. Other plants may be designed to detect and signal the presence of explosives in the soil, which can help to find land mines in war zones. Land mines often leak TNT (trinitrotoluene, a yellow flammable compound) into the soil. Scientists hope that seeds could be someday designed to change color when scattered over mine fields.

Many other valuable benefits can be realized from research into sentinel plants. Besides anti-terrorism, sentinel plants could be used to detect naturally occurring diseases, discover toxins, and monitor pollution, just to name a few.

Sentinel plants could also be used in agriculture. Plants could sense and respond to insects, poor soils, dry or wet conditions, and other environmental problems. For example, if sentinel plants find a pest in one part of a field, a farmer would only need to spray that particular area. In this way, the farmer saves money by not spraying the entire field. With the use of sentinel plants, farmers could also tell when fruit is ripe in order to harvest it at its peak of flavor.

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[*See Also* **Vol. 2, Biological Pest Control; Vol. 3, Biological Weapons; Vol. 3, Explosives, Bioremediation of; Vol. 3, Security-Related Biotechnology.**]

Soap-Making

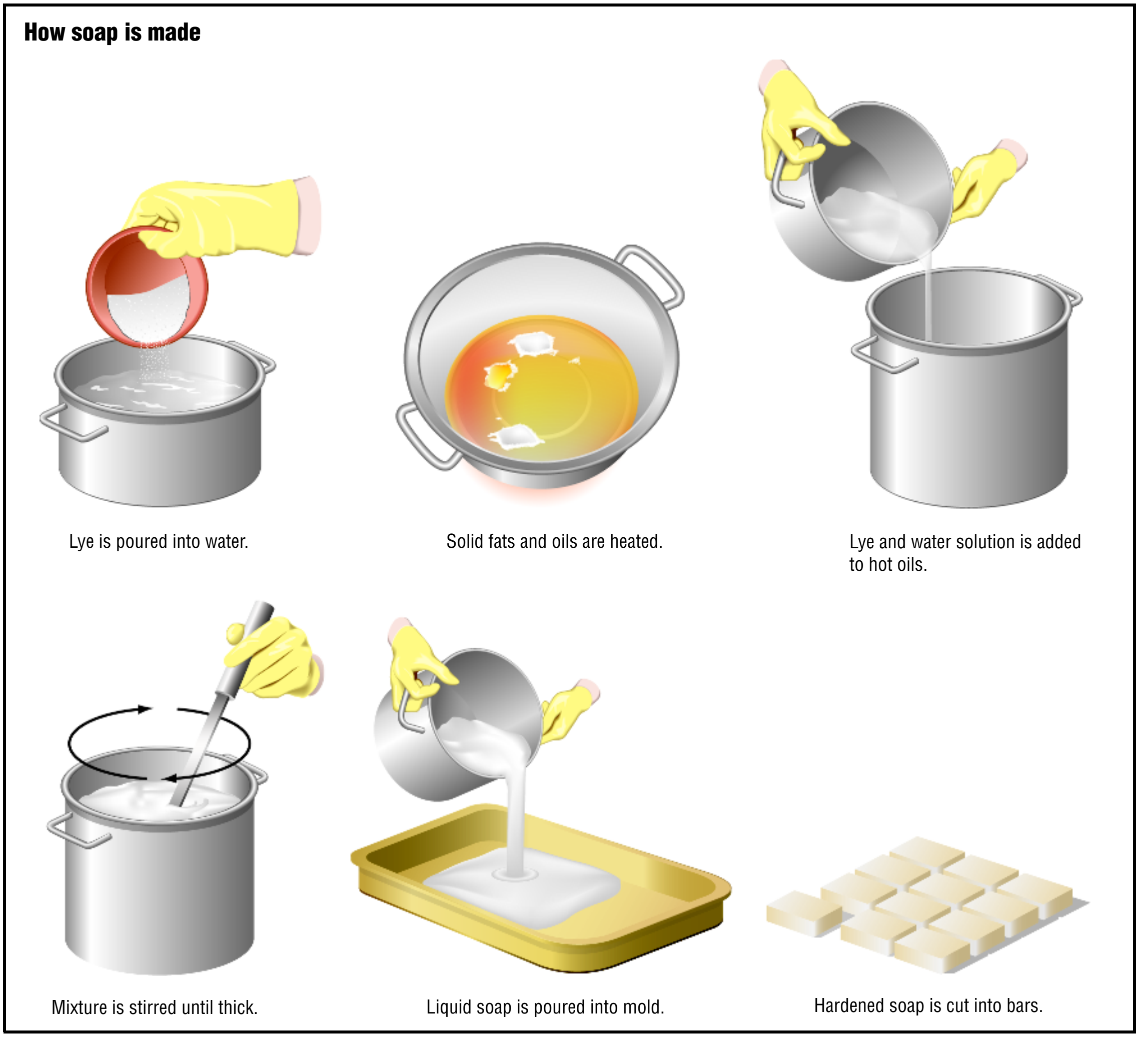
Description

Humans have made soap for thousands of years. In ancient times, soap was made with a substance called potash, obtained from a wood fire, and fats or oils. In modern times, soap is made as a liquid, solid, or powdered mixture of ingredients that are chemically similar to those used in ancient times.

A key ingredient in soap is a chemical called an alkali. An alkali is a molecule that contains atoms of a metal, such as sodium or potassium, along with atoms of hydrogen and oxygen. Alkalis are strong chemicals that give soap its slippery feel between the fingers. To make soap, the alkali is heated with animal or vegetable oils or fats to a temperature of around 175 to 212 degrees Farenheit (80 to 100 degrees Celcius), resulting in a chemical process known as saponifiation. The oils or fats and alkali react with water to produce glycerol (a sweet, oily chemical) and soap. Glycerol is also known as glycerin, and many soaps contain glycerin.

Scientific Foundations

Soap is a compound used with water to clean. When it reacts with water, dirt is lifted into the resulting foam, or lather. Soaps differ mainly in the lathering properties of the fats or oils and according to the particular alkali used. Fats and oils used in soapmaking include grease, fish oils, tallow (hard animal fat), and vegetable oils. When sodium hydroxide is used, hard soap is formed. Soft soap results when potassium hydroxide is used. Aluminum, calcium, lead, and other metals are used instead of sodium or potassium for soaps in products such as lubricating greases and ointments. Fillers are added to soaps to increase their


How soap is made
Lye is poured into water.
Solid fats and oils are heated.
Lye and water solution is added to hot oils.
Mixture is stirred until thick.
Liquid soap is poured into mold.
Hardened soap is cut into bars.

Soap-making is an age-old process that can be altered in a variety of ways. Often, perfumes or coloring is added to soap. *Illustration by GGS Inc.*

ability to lather and clean. Perfumes and scents are also sometimes added.

Development

The earliest use of soap occurred around 2800 BCE when the Babylonians mixed fats and salts to make bathing soap. The ancient Egyptians made a soap-like substance for cleaning, and around the first century CE, writings show that soaps were used to clean hair. By the second century, Greek physicians recommended soap as part of medical treatments. In the seventh century, soap-making was common in the Middle East and Europe. The soaps were colored, con-

People in the Late Middle Ages Did Not Bathe with Soap

In the last part of the Middle Ages, which lasted from about 1300 to 1450, people stopped bathing because they thought it led to contagious diseases (called plagues) that sometimes killed off whole communities of people. Before that time, most people used public bathhouses. When diseases spread across Europe during the Middle Ages, the public bathhouses were closed because it was believed they helped spread the diseases. Although soap was no longer used for bathing, it was still commonly used to clean clothes and other materials. Instead of bathing, most people used perfumes and scents. Unfortunately, the lack of bathing with soap did just the opposite to what people believed—it added to the spread of diseases.

tained perfumes, came in liquid and solid forms, and were sometimes used for shaving. By the eighth century, soap-making occurred mostly in western Europe, especially France, Italy, and Spain. Many soaps were made with goat tallow and beech ash.

Around the thirteenth century, the French learned to make soap with olive oil (what is now called castile soap) instead of with animal fat. The French method was taken to England in the sixteenth century—an improvement over current English techniques. The first English patent for soap was made in the seventeenth century. In 1783, Swedish chemist Carl Wilhelm Scheele (1742–1786) developed the boiling process that is used today to make soap. Scheele boiled olive oil with lead oxide to produce glycerin and soap.

In 1791, French chemist Nicolas Leblanc (1742–1806) discovered the process for making sodium carbonate, or soda ash, from ordinary salt. (Sodium carbonate is a chemical made of atoms of sodium, carbon, hydrogen, and oxygen.) This process allowed soap to be made less expensively and, thus, made it profitable to make in large manufacturing facilities. In 1823, Chevreul found that simple fats do not mix with alkali to form soap, but are first broken apart to make fatty acids and glycerol. This discovery helped scientists understand the chemistry behind soap-making.

The U.S. colonists and their descendants made soap from waste fats and lye. Lye, which is chemically identical to potassium hydroxide, was obtained by running water through wood ashes in a process called leaching. Belgian chemist Ernest Solvay (1832–1922) invented a process using ammonia to further reduce the cost of soap-making, along with making it a better quality. These

Words to Know

Alkali: A water-soluble material (a material that can be dissolved in water) that comes from ash after vegetation or wood is burned.

Atom: Small, indestructible particles, composed of protons, neutrons, and electrons, from which all elements are made.

Leaching: The movement of dissolved chemicals with water percolating through soil.

Metal: An opaque lustrous elemental chemical substance that is a good conductor of heat and electricity, and when polished a good reflector of light.

Molecule: A chemical combination of atoms, and the smallest amount of a chemical substance.

Saponification: A chemical reaction involving the breakdown of triglycerides to component fatty acids, and the conversion of these acids to soap.

Synthetic: Referring to a substance that either reproduces a natural product or that is a unique material not found in nature, and which is produced by means of chemical reactions.

improvements made soap-making one of the biggest industries in the United States by the middle part of the nineteenth century.

The use of soap remained basically the same between the 1850s and the 1910s. Then, synthetic (chemical-based) detergent was developed in Germany as a substitute for soap, which was in low supply due to World War I. Detergents, which do not contain soap, are combined chemically with a variety of materials. In the United States, detergents began replacing soaps in the early 1930s, and they outsold soaps by the 1950s. In the 2000s, detergents have, for the most part, replaced soaps for dishwashing, cleaning, and laundering.

Current Issues

In the United States and other developed countries, synthetic detergents have mostly replaced soaps because they are less costly and easier to manufacture, and more effective to use. However, they have had a negative impact on the environment. Before the 1970s, many detergents included phosphates, which are various compounds that contain phosphoric acid. Water pollution occurred when wastewater was shown to contain phosphates from cleaning products. When this happened, algae in the wastewater grew faster as they ate the phosphates. They then used up all the oxygen, which killed off other living things in the water. In the late 1960s and early 1970s, phosphates began to be removed from detergents. In the 2000s, biodegradeable materials—those that are safely removed by bacteria—have replaced phosphates.

Some controversy has occurred with propylene glycol being used in soap, along with other products such as toothpaste. Propylene glycol is a colorless ingredient that helps moisture stay in products. Some of the controversy with proplylene glycol occurred because of its similarity to ethylene glycol, a known toxin. Exposure to large amounts of ethylene glycol can damage human organs. The U.S. Food and Drug Administration (FDA) generally approves propylene glycol as safe for use as an additive in food.

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[*See Also* **Vol. 3, Antimicrobial Soaps; Vol. 3, Cosmetics; Vol. 3, Laundry Detergents; Vol. 2, Vegetable Oils.**]

Soil-Modifying Bacteria

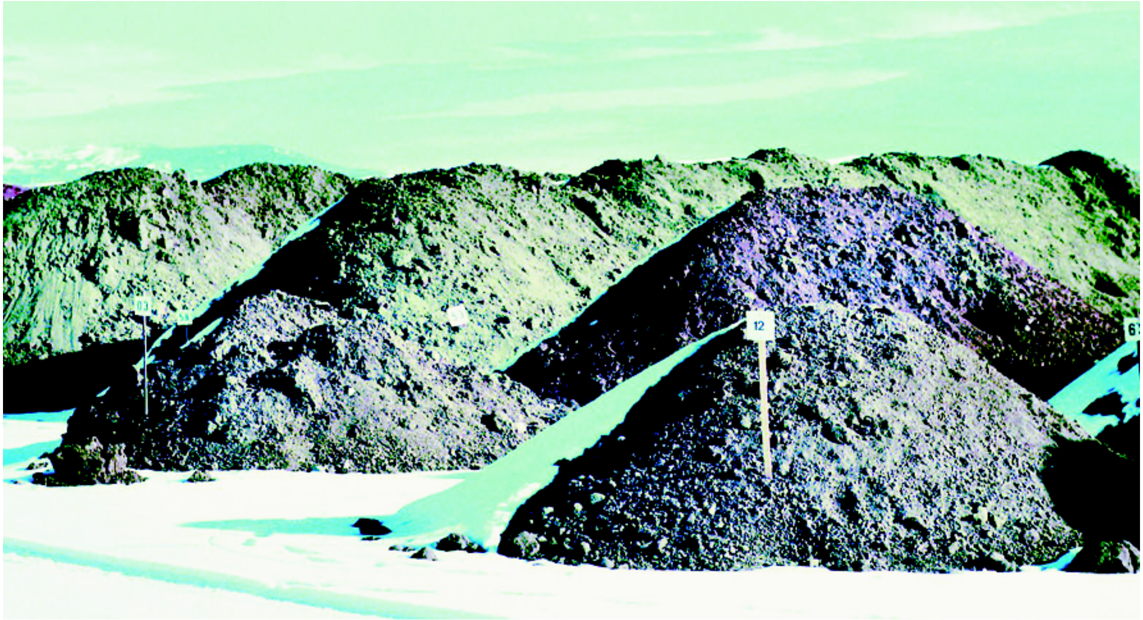
Description

Bacteria are tiny organisms (microorganisms) that live in most places on Earth. Some cause disease in plants and animals, but many can be beneficial. Bacteria that can change the properties of soil through their metabolic activities (they way they break down nutrients) are known as soil-modifying bacteria. Certain types of these bacteria and other microorganisms can remove toxins (poisons) from contaminated soil by breaking down the contaminant. Uncontaminated soil also supports the growth of bacteria, which degrade organic material in the soil, releasing compounds. The result can be a nutrient-rich medium for crop plants.

Scientific Foundations

In the context of biotechnology, soil-modifying bacteria are employed in a treatment process known as bioremediation. This process relies on the use of naturally occurring soil bacteria to convert a hazardous compound into a less hazardous or completely nontoxic compound. Some naturally occurring soil bacteria have the ability to break down a wide variety of compounds, including toxic compounds. However, contamination of soil with human-made chemicals, such as gasoline and polychlorinated biphenyls (PCBs, chemicals that used to be used as coolants), can best be handled by bacteria that have been genetically engineered.

To create these genetically engineered bacteria, a gene from another organism is selected and transplanted into the bacteria. Genes are sections of DNA (deoxyribonucleic acid, the genetic material in nearly all cells) that contain a recipe, or code, for cells to produce proteins. Proteins are the main components of cells and control most of their



Piles of dirt contaminated with petroleum. The dirt will be injected with special bacteria that can digest the petroleum products. *AP/ Wide World.*

functions. By finding a protein that breaks down a particular toxin and matching that protein to a gene, scientists can program bacteria to use the toxin as a food source with the transplanted gene. Such bacteria are called transgenic bacteria.

When naturally occurring soil bacteria grow in the presence of increasing concentrations of a target toxic compound, those bacteria in the population that are best able to break down the toxin have a survival advantage. These bacteria may be able to adapt to the stress of the toxic compound by expressing or increasing the expression of a gene that codes for a protein that directly breaks down the toxin. The bacteria can also alter the bacterial surface so that the compound can more easily enter the bacterial cell, where a specific chemical can subsequently digest it. Alternately, a transgenic, soil-modifying bacterium can be created using the techniques of recombinant DNA technology. In this case, a gene can be incorporated into the DNA of a soil bacterium, such as *Pseudomonas aeruginosa*, that allows it to digest the toxin that is contaminating the soil.

Treatment of contaminated soil using soil-modifying bacteria typically involves the addition of nutrients to the soil by drilling a hole into the contaminated soil and pumping in nutrient-laden water. The nutrients stimulate the accelerated growth of bacteria already present, and their growth can lead to increased breakdown of the soil contaminant. Genetically altered bacteria also can be

Landfarming

Detoxification of soil using soil-modifying bacteria allows contaminated soil to be removed from the site of a spill, decontaminated, and either returned to the original site or used to supplement the soil at another location. This practice has been termed landfarming. While potentially useful, landfarming is usually not welcome by those in the immediate area intended for landfarming. As with other aspects of environmental biotechnology, landfarming must meet guidelines that ensure its safety.

pumped into the soil. This treatment can be done at the site of a spill, without disturbing the contaminated soil. However, for small spills, it may be easier to remove the contaminated soil and transport it to another location for treatment.

Development

The ability of soil modifying bacteria to clean-up contaminated soil was demonstrated in the aftermath of the Exxon *Valdez* oil spill on the coast of Alaska in 1989. Application of bacteria to the contaminated soil reduced the level of toxicity. Since then, species of naturally occurring soil bacteria that are particularly good at breaking down contaminants have been identified and genetically engineered bacteria have also been created to expand the types of soil-modifying bacteria available for bioremediation.

Soil-modifying bacteria are also critical in the composting of organic material. Composting involves the activities of a number of bacteria. Initially, the breakdown of organic material occurs near the edges of the collected material, and is mainly due to common soil bacteria that can operate in the presence of oxygen. Later, and particularly with a larger mound of material, composting of the buried material involves the action of bacteria that can operate in an environment that is reduced or nearly devoid of oxygen. As well, bacteria that are more resistant to heat become more dominant with time, as the decomposition process generates heat. While composting has been practiced for millions of years, in the past few generations its use has become much more prevalent. Many municipalities now have organized composting programs, and domestic composting is commonplace.

Current Issues

Some people are concerned that releasing transgenic, soil-modifying bacteria into the environment could have unanticipated or negative

Words to Know

Bioremediation: The use of living organisms to help repair damage.

Composting: The process by which organic waste, such as yard waste, food waste, and paper, is broken down by microorganisms and turned into a useful product for improving soil.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Metabolism: Chemical changes in body tissue that convert nutrients into energy for use by all vital bodily functions.

Toxin: A poison that is produced by a living organism.

consequences. While this possibility does exist, the bacteria that are used to degrade soil contaminants have usually evolved to be capable of using the contaminant as a nutrient source. Indeed, this requirement can be absolute; in the absence of the contaminant compound, the bacteria die. Thus, the likelihood that the bacteria will spread to other niches in the soil is remote.

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[*See Also* **Vol. 3, Bioremediation; Vol. 2, Compost/Organic Fertilizers.**]

Soybeans, Genetically Engineered

Description

The soybean plant is related to alfalfa, clover, and peas. It was grown in China at least 5,000 years ago and is one of the most widely raised crops in the world today. Soybeans are squeezed to extract their vegetable oil, ground to make flour, and processed (especially in Asia) to make tofu, tempeh, and soy milk. They also are used as animal feed. In the United States, soybeans are the second-largest crop. (Corn is the largest crop.) Genetically engineered soybeans are soybeans that have had their DNA (deoxyribonucleic acid, their genetic information) changed in the laboratory.

The world's largest growers of soybeans are the United States, Brazil, Argentina, and China. About 40 percent of the world's soybean crop is grown in the United States, and over 80 percent of the U.S. crop is genetically engineered. As of 2006, all the genetically engineered soybeans being grown were a type called Roundup Ready®. Roundup®, which was invented by the Monsanto company in the 1970s, is a brand name for the herbicide glyphosate. A herbicide is a chemical that kills plants, especially weeds. If a field of Roundup Ready soybean plants is sprayed with glyphosate, only the weeds will die, not the soybean plants. This gives the soybeans a chance to grow better, so farmers can get more soybeans from each acre than they would otherwise.

Farmers who want to grow Roundup Ready® soybeans must buy their seeds from Monsanto, which is the only legal manufacturer of Roundup Ready seeds. When Monsanto sells seeds, it makes the farmer sign a contract saying that they will not save seeds from their crop and plant them the next year. This way, Monsanto can sell the farmers fresh seeds every year, which is more profitable.

Test plots of genetically modified soybeans in Iowa. *Kent Foster/Photo Researchers, Inc.*

Roundup Ready® soybeans are not the only kind of genetically engineered soybean. Soybeans have also been genetically engineered to be resistant to the herbicide glufosinate. However, all of the genetically engineered soybeans being grown for sale in 2006 were Roundup Ready.

Scientific Foundations

Almost all living cells contain DNA molecules. These contain all the information that the organism needs to make offspring. DNA also tells each cell how to make all the materials that it needs throughout its life. A set of instructions to create a specific chemical is contained in a single gene, or section of DNA. In nature, changes in DNA happen slowly over time. However, genetic engineers can quickly add one or many genes to an organism's DNA.

Genes can be added to a plant's DNA in several ways. The most common is to shoot them into the cell using a special kind of shotgun called a gene gun. This gun shoots tiny metal bullets coated with copies of a gene into cells. Some copies of the gene get stuck in the cell and may get added to the cell's DNA. Viruses

Monsanto Wants a Slice of the Bean

Argentina is the world's third largest producer of soybeans. More than half the land farmed in Argentina is used to grow soybeans, and 98 percent of those soybeans are the genetically engineered Roundup Ready® type developed by the Monsanto company. However, Argentina's government does not recognize Monsanto's patent on the Roundup Ready technology, and Monsanto stopped selling the Roundup Ready soybeans in Argentina in 2004. Farmers in Argentina are continuing to grow soybeans by buying seeds illegally. In 2006, Monsanto sued European importers of Argentinian soybeans to demand a share of the profits.

can also be used to change DNA because some viruses reproduce by changing the DNA of the cells they infect, forcing the cells to make copies of the virus. Roundup Ready soybeans were created using the gene-gun method.

The DNA that is added to a genetically engineered plant or animal can come from a completely different kind of organism. For example, DNA from a human begin can be added to a rice plant, or DNA from a bacterium (a very small, usually single-celled organism) can be added to a soybean plan. The gene that makes soybean plants Roundup Ready® comes from a bacterium.

Development

A number of crops have been genetically engineered since the 1980s besides soybeans, including alfalfa, corn, cotton, papaya, rice, squash, and wheat. Herbicide resistance is only one of the traits or abilities that can added to a genetically engineered plant. Plants also have been engineered to grow better in salty soil, to make substances in their leaves to poison insects (insecticides), to have more of certain vitamins, or to have other characteristics.

Roundup Ready® soybeans were first grown for sale in 1996. The new soybeans were popular with American farmers. By 1999, over 60 percent of the U.S. soybean crop was Roundup Ready. By 2003, over half the soybeans in the world were genetically engineered Roundup Ready soybeans.

Current Issues

Supporters of Roundup Ready® soybeans argue that they help reduce erosion (removal of soil by wind and rain) because Roundup Ready soybeans can be planted by simply throwing them

Words to Know

Biodiversity: Literally, ''life diversity'': the number of different kinds of living things. The more different kinds, the greater the biodiversity.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Gene gun: A device that shoots tiny metal bullets coated with DNA fragments into cells in order to alter their DNA permanently.

Glyphosate: A weed-killing chemical; the world's most-used herbicide.

Herbicide: A chemical substance used to kill weeds or undesirable plants.

Mutation: A change in a gene's DNA. Whether a mutation is harmful is determined by the effect on the product for which the gene codes.

on the ground, rather than plowing up the soil. They also argue that the amount of soybeans harvested from each acre planted is higher for genetically engineered soybeans, and that farmers can make more money planting them. Supporters also point out that there is no scientific evidence that genetically engineered soybeans are bad for people, although one widely quoted study published in 1999 found that they are less nutritious than regular soybeans. From the point of view of supporters of genetic engineering, people who object to genetically engineered crops have little reason to do so.

Opponents of genetically engineered crops argue that such crops may cause genetic pollution, that is, that altered genes from genetically engineered crops might get into the DNA of other crop plants or wild plants. They also say there will be effects on the environment even if genetic pollution does not happen. For example, in 2003, a three-year British government study found that growing Roundup Ready® crops reduces the biodiversity of the area where they are grown because Roundup Ready plants enable farmers to kill almost all the weeds in their fields. (Biodiversity is the number of insects, birds, and other organisms that live in an area.)

Also in 2003, scientists reported that weeds were quickly becoming Roundup Ready® too. The more Roundup is used by farmers—and the whole point of having Roundup Ready crop varieties is to use more Roundup—the quicker weeds evolve immunity to it. Since Roundup (glyphosate) is the most popular herbicide in the world and one of the least poisonous, the appearance of glyphosate-resistant weeds could force farmers to shift to more toxic chemicals.

Dr. Stephen Powles, an Australian glyphosate-resistance expert and supporter of genetically engineered crops, said in 2005 that "[W]e are over-using this great resource and resistance is appearing worldwide, especially in the U.S., where glyphosate-resistant soybeans, cotton, and corn are dominant."

Some experts say that the day when Roundup® no longer works can be put off by using what is called "resistance management." One form of resistance management is to grow a Roundup Ready® crop every other year, alternating it with a non-Round Ready variety of the crop and some other herbicide. This would mean using more toxic, non-Roundup herbicides right away, but would keep Roundup working longer.

The debate between supporters and foes of genetically engineered crops will continue. As of 2006, more than 60 percent of packaged foods in U.S. supermarkets already contained genetically engineered ingredients.

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[*See Also* **Vol. 2, Cotton, Genetically Engineered; Vol. 2, Genetic Pollution; Vol. 2, Rice, Genetically Engineered; Vol. 2, Tomato, Genetically Engineered; Vol. 2, Transgenic Plants.**]

Sugar Substitutes

Description

Sugar substitutes are products created in a laboratory that are designed to taste sweet. Sugar substitutes are sometimes called artificial sweeteners. They are used in foods and drinks that are low-calorie, for people who want to lose weight; or low-sugar, for people with the medical conditions like diabetes, who cannot eat large amounts of table sugar.

Unlike natural sugar, sugar substitutes do not contain calories, or have very few calories. They are often added to diet foods and beverages such as soda. Sugar substitutes are also much sweeter than regular sugar, so people only need to use a small amount to get a similar taste. The extra sweetening power means manufacturers do not need to use as much as they would if they used regular sugar. This saves them money.

There are many different types of sugar substitutes. The five approved for use in the United States are:

- Saccharin
- Aspartame
- Sucralose
- Acesulfame potassium (also called acesulfame-K)
- Neotame.

Saccharin, aspartame, and sucralose all come in a powder form that people can mix in their drinks and foods.

Saccharin is can be found in many products worldwide, including the sugar substitute Sweet 'n Low®. It is 300 to 700 times sweeter than regular sugar. Saccharin stays sweet in both hot and cold drinks.

The three main varieties of sugar substitute on the market: Splenda® (sucralose), Equal® (aspartame), and Sweet 'n Low® (saccharin). © *Octane Photographic.*

Aspartame is the sweetening ingredient in Equal® and NutraSweet®. This type of sugar substitute is about 200 times sweeter than regular sugar. However, aspartame loses its sweet taste when heated, so it is not a good sugar substitute for baking.

Sucralose is one of the newest types of sugar substitutes, and is commonly called Splenda®. It is about 600 times sweeter than regular sugar. Unlike saccharin and aspartame, sucralose is made from natural sugar. But, because it still is created through a chemical process, it is considered an artificial sweetener. Sucralose stays sweet when heated, and can be used for cooking and baking.

Neotame is a super-sweet product is added to sugarless chewing gum, jams, jellies, and other ready-to-eat foods. This sweetener is 7,000 to 13,000 times sweeter than regular sugar.

Acesulfame potassium is among the least sweet of the sugar substitutes. It is about 200 times sweeter than regular sugar. Manufacturers add this artificial sweetener to products such as cookies and candies. It is sold under the brand name Sunett®, among others.

Cyclamate is a sugar substitute that became unavailable in the United States in 1970 because animal studies showed it caused cancer. However, it is still used in many other countries around the world. Cyclamate is about 30 times sweeter than table sugar. Alitame

Insatiable Sweet Tooth

Americans are the largest consumers of artificial sweeteners in the world, although their use is also climbing in Europe. Each year, the average American consumes about fifty pounds (23 kilograms) of artificial sweeteners, and this is in addition to, rather than instead of, about ninety pounds (41 kilograms) of natural sugars. America's sweet tooth is contributing to the growing problem of an overweight population.

(Aclame^{TM}) is another artificial sweetener used in Australia, New Zealand, Mexico, China, and other countries, but not in the United States. It is 2,000 times sweeter than regular sugar.

Development

Saccharin is the oldest type of sugar substitute. Chemists Ira Remsen and Constantine Fahlberg accidentally discovered it in 1879. One of the men noticed his fingers tasted sweet after working with chemicals to make a brownish-black liquid called coal tar. The two scientists published an article about their discovery in 1880. Fahlberg later took full credit of the discovery and never mentioned Remsen. During World War I (1915–1918) and World War II (1938–1941), people used saccharin when natural sugar was in short supply. Saccharin was the only alternative to sugar in the United States for many decades.

Scientific Foundations

In 1965, chemist James M. Schlatter noticed that two chemicals he mixed together (asparatic acid and phenylalanine) tasted sweet. The result was the second sugar substitute approved in the United States, aspartame. In 1981, the Food and Drug Administration (FDA) said aspartame was safe to use in foods.

Sucralose was invented by researchers in London. They made this sugar substitute by replacing some molecules in regular table sugar (sucrose) with three chlorine atoms. The FDA approved sucralose in 1998.

Neotame was developed by the Monsanto chemical company in California. Researchers there added a chemical called 3-dimethylbutyl to the already approved sweetener aspartame. Unlike aspartame, neotame kept its flavor during cooking. The FDA approved neotame in 2002 for use by food and drink makers. It is not approved for use by the general public.

Words to Know

Diabetes: A disease in which the body cannot make or properly use the hormone, insulin.

Phenylketonuria: A genetic disorder in which human body fails to produce the enzyme that breaks down phenyalanine. Accumulation of phenylalanine causes brain damage.

Although scientists at the chemical company Hoechst discovered acesulfame potassium (acesulfame K) in 1967, the FDA did not approve this artificial sweetener until 1998, when it was added to sodas. In 2003, the FDA said the product was okay for general use. Research has shown that acesulfame K works well in fruity drinks, dairy products, and baked goods, as well as personal care products like toothpaste and mouthwash.

Current Issues

The American Heart Association and American Diabetics Association say the approved sugar substitutes are a good choice for people with diabetes, because the products do not raise the amount of sugar in the blood. People with diabetes must control their intake of sugar because their pancreas is unable to make enough insulin, the body's natural regulator of carbohydrates (sugars and starches), and the glucose (a simple sugar) that is formed when carbohydrates are digested.

Since the introduction of saccharin, there has always been controversy surrounding artificial sweeteners. Early studies involving saccharin and aspartame found that the products cause cancer in rats, but only after the animals were given extremely large amounts of the sugar substitutes. In 1958, the U.S. Congress passed a new law called the Saccharin Study and Labeling Act, which meant that any foods containing saccharin would undergo close review, and had to carry a label that said "Use of this product may be hazardous to your health. This product contains saccharin which has been determined to cause cancer in laboratory animals."

In the 1970s, the FDA started reviewing scientific information about saccharin. Studies released at this time said that rats that were fed saccharin developed bladder cancer. However, other researchers said the cancer was caused by other unpure substances. Canada banned use of saccharin in 1977.

Similar concerns have been raised about aspartame. Some safety tests suggested the sugar substitute caused brain tumors in rats. The finding delayed approval for aspartame for quite some time. Some experts say there has been an increase in brain cancer in the United States since the product's approval.

However, some sweeteners may cause other health problems such as headaches and stomach aches. Any products containing aspartame must carry a label saying the ingredient is dangerous for those with phenylketonuria, a disease passed down through families that causes dangerous levels of phenylalanine to build up in the blood. Aspartame, when it is broken down by the body, causes phenylalanine to be released into the blood. Untreated, the disease can cause brain damage.

Despite concerns about safety, the U.S. National Institutes of Health says there is no real evidence to show that the artificial sweeteners approved for use in the United States cause cancer.

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[*See Also* **Vol. 2, Fat Substitutes.**]

Terminator Technology

Description

Terminator technology is type of genetic engineering applied to plants. It is called "terminator" technology because it makes the seeds of the plants sterile—that is, new plants will not grow from them.

Terminator technology is also called genetic use restriction technology (GURT for short) because its main purpose is to keep farmers from using seeds that they have raised themselves. Companies who make genetically engineered plants want to sell new seeds to farmers every year; they do not want farmers to save seed from their own crop and use it the next year. Terminator technology would force farmers to buy new seeds every year by making harvested seeds useless.

One puzzle about terminator seeds is how to make them in the first place. If a plant's seeds are all sterile, then where did the seeds come from? Genetic engineers get around this problem by engineering the plant's genes in such a way that the plant produces a chemical that kills the seed when it is almost ripe. However, this chemical is made by the plant only if the other parts of the terminator system are in place.

Scientific Foundations

Most of the cells in any organism contain all the DNA molecules it needs to make offspring. DNA (short for deoxyribonucleic acid) also acts like a book of recipes, telling each cell exactly how to make thousands of protein molecules that it needs to live. In nature, DNA changes slowly over time. Genetic engineering, however, can change DNA overnight by directly inserting new genes. The most common way of doing this is to shoot thousands of copies of a gene (a single piece of DNA) into a cell and see if some of them end up in the cell's own DNA. To make a terminator-technology variety of a plant, scientists must add at least five new genes to its DNA.

This is a simplified version of how one kind of terminator technology works:

Step 1. A newly added gene tells the plant's cells to make a certain protein (a kind of large molecule) and is called the *coding sequence*. The protein kills the plant's seeds just as they finish ripening.

Step 2. The protein does not actually get made, however, unless a gene that goes with it, a *promoter* gene, tells the cell to do what the coding sequence says.

Step 3. Genetic engineers also add a gene that prevents the promoter from turning the seed-killing protein on. This acts as a guard or block gene.

Step 4. The blocking gene can be removed by a substance called recombinase, which is also made in the cell. In a terminator-technology plant, these genes are all arranged so that when the plant grows normally from a seed and makes new seeds, recombinase is not made, and the seeds are fine.

Step 5. Before a company sells terminator-technology seeds to a farmer, it sprays the seeds with a special chemical that lets the cell make recombinase. This takes the blocking gene out of the way, and the plants make the seed-killing protein. The farmer cannot grow a new crop from saved seeds but must buy more seeds from the company.

Development

Terminator technology was not possible until the 1990s. The structure of DNA itself was not understood until the early 1950s. In the 1960s and 1970s, chemicals were discovered that allowed scientists to cut and copy pieces of DNA. Finally, in the 1980s, ways of getting particular genes into the DNA of living cells were perfected. It became possible to take a gene from one kind of organism and put it into the DNA of a completely different kind of organism. Such an organism is called transgenic, genetically engineered, or genetically modified. In the late 1980s and early 1990s, scientists working for large corporations and for some governments produced genetically modified crop plants. Today, most of the corn, cotton, and soybeans grown in the United States is genetically engineered.

Reading the Fine Print

In 2006, terminator technology was still not a part of any genetically engineered crop being sold or tested in open fields. Instead, farmers who buy genetically engineered seeds must sign a contract, called a Technology Agreement, which says that they will notsave genetically engineered seeds. The contract also gives the company the right to look at aerial photographs of the farm and to examine and copy any documents that the farmer owns that have to do with growing their crops. Monsanto has sued farmers that it said were using its genetically modified plants without permission.

Terminator technology was developed in the 1990s by a company called Delta and Pine Land Company, with help from the U.S. Department of Agriculture. Delta and Pine Land was soon bought by the Monsanto, a leader in the genetic engineering of plants.

Current Issues

When terminator seeds were first introduced, public reaction to the terminator technology was very negative. In fact, the phrase “terminator technology” was invented by critics of the technology. Critics said that terminator seeds could turn 1.4 billion poor farmers, especially in Asia, Africa, and Latin America, into virtual slaves of large, powerful companies like Monsanto because they would be forced to buy seeds every year. Traditional farmers have customs of sharing and trading seeds that go back for centuries; these customs could not survive widespread use of terminator seeds, which would contribute to the loss of local varieties developed by farmers over thousands of years. Terminator technology is therefore (according to its critics) a danger to biodiversity, the number of different kinds of crops or other living things there are in a given area. In 1999, Monsanto promised publicly to not use terminator technology in the seeds it sells. Other companies, such as Syngenta, that have also developed terminator technologies, have made no such promise.

The controversy over terminator technology did not end in 1999. In the following years, both Monsanto and the governments of the United States and Canada pushed for official acceptance of the terminator technology. They argued that it was necessary to protect corporate profits and that it would help keep engineered genes from polluting the environment. In 2000, 187 countries that had signed a treaty called the United Nations Convention on Biological Diversity agreed that sterile seed technologies like the terminator should not be used, at least for the moment. They reaffirmed that vote in March

Words to Know

Biodiversity: Literally, ''life diversity'': the number of different kinds of living things. The more different kinds, the greater the biodiversity.

Coding sequence: A gene that produces a protein when triggered by a promoter gene.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Gene use restriction technology (GURT): A form of genetic engineering that allows traits in plants to be turned on or off using chemicals or other means. Terminator technology is a form of GURT.

Promoter: A gene that makes the cell produce the protein described by a second gene.

Technology agreement: A contract signed by a farmer in order to buy seed from a genetic engineering company. The farmer agrees to not use seed harvested from the genetically engineered crop.

2006, one month after Monsanto announced that it would feel free to use terminator technology in non-food crops like cotton. The United States is not a party to the Convention.

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[*See Also* **Vol. 2, Transgenic Plants; Vol. 2, Genetic Pollution.**]

Tomato, Genetically Engineered

Description

The tomato is a fruit native to South America that is rich in vitamin C. Genetically engineered tomatoes are tomatoes whose DNA (deoxyribonucleic acid, its genetic information) has been changed in the laboratory.

Compared to genetically engineered corn, rice, cotton, and alfalfa, which are grown in many countries, genetically engineered tomatoes have been a failure. Genetically engineered tomatoes were grown from 1994 to 1999, but none have been grown for sale since then. However, genetically engineered tomatoes are important because of their place in the history of genetically engineered foods. A genetically engineered tomato, the Flavr Savr tomato created by the Calgene company, was the first genetically engineered food to be sold anywhere in the world.

Usually, tomatoes that will be sold in stores are picked green (unripe) because they stay intact and survive long-distance shipping better than ripe, red tomatoes. After shipping, green tomatoes are placed in special ripening rooms where they are exposed to ethylene gas to make them ripen. The Flavr Savr tomato was genetically engineered to ripen more slowly. It could be picked when partly ripe, then shipped directly to stores. By the time Flavr Savr tomatoes were on the shelf, they were ready to eat. Since no ethylene ripening was needed, the Flavr Savr was cheaper.

However, the Flavr Savr tomato turned out to be difficult to ship without damage because they were softer than green tomatoes, increasing costs. Also, in 1995, Calgene was sued by the Monsanto company for copyright infringement (stealing its scientific ideas). Even though the tomatoes sold well, Calgene was having trouble

Researchers harvesting the first crop of tomatoes genetically modified to be resistant to the mottle virus, which infects tomatoes. *AP images.*

making money. In 1997, Calgene gave up and the Flavr Savr tomato disappeared from the U.S. market.

Although delayed-ripening genetically engineered tomatoes disappeared from stores in the 1990s, research on genetic engineering of tomatoes did not stop. In 2001, researchers at the University of California at Davis announced that they had engineered a salt-tolerant tomato. The new tomatoes could grow well in water so salty that ordinary tomatoes could barely live in it. Since many soils around the world have salt in them—often because of irrigation, the practice of piping water to fields from distant rivers, where it dries up and leaves its salt in place—such a plant might be grown in places where no tomatoes can now be grown.

The number of genetically modified fruits and vegetables being field-tested in the United States has decreased greatly since the 1990s.

Times Change

In 1997, the Zeneca company began selling canned tomato puree (ground-up tomatoes) in Britain. The puree was made from genetically engineered tomatoes that were grown and canned in California and then shipped across the Atlantic Ocean. This was the first genetically engineered food sold in Europe. The cans were marked clearly on the label MADE WITH GENETICALLY MODIFIED TOMATOES and were cheaper by weight than cans of regular (non-genetically engineered) tomato puree. The product was popular with British shoppers, who bought all that Zeneca could make. However, British feeling toward genetically engineered food changed. In 1996, only 8 percent of Britons said they did not want to eat genetically engineered food; by 1998 the number was 61 percent. In 1999, British stores stopped selling the genetically engineered tomato puree—permanently.

In 1999, 120 were being tested; by 2003, only 20. It does not seem likely that genetically engineered tomatoes are going to reappear on supermarket shelves in the United States any time soon.

Scientific Foundations

Almost all living cells contain a complete set of the DNA molecules that the organism needs to reproduce. DNA also tells each cell exactly how to make all the materials that it needs to live. A set of instructions to create a specific chemical is contained in a single gene, or section of DNA. In nature, changes in DNA happen slowly over time. Genetic engineering, on the other hand, can change a plant or animal's DNA overnight by adding new genes directly.

Genes can be added to a plant's DNA in several ways. The most common is to shoot them into the cell using a special gun. Another method is to put the gene into a virus and let the virus infect the cell whose DNA is to be changed. Viruses can be used to change DNA because that is what they naturally do—a virus reproduces by changing the DNA of the cells it infects, forcing them to make copies of the virus. Bacteria have also been used to deliver new genes to plant cells. The bacteria method was used to make the Flavr Savr tomato.

Development

The Flavr Savr tomato was developed by Calgene with support from the Campbell Soup Company. Campbell was also supporting a British company, Zeneca Seeds, which had been engineering a

Words to Know

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Ethylene: A gas used to make tomatoes ripen quickly.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Mutation: A change in a gene's DNA. Whether a mutation is harmful is determined by the effect on the product for which the gene codes.

Restriction enzyme: A special type of protein that can recognize and cut DNA at certain sequences of bases to help scientists separate out a specific gene.

Irrigation: The transport of water through ditches or pipes to fields to water crops.

different delayed-ripening tomato since the late 1980s. To avoid competition, Calgene and Zeneca agreed that Calgene would be given worldwide rights to sell its fresh, whole Flavr Savr tomato in stores, while Zeneca would be allowed to sell tomato paste, ketchup, and sauce made using its own variety of delayed-ripening tomato (very similar to the Flavr Savr). The U.S. Food and Drug Administration (FDA, an arm of the United States federal government) said that Calgene could grow and sell the Flavr Savr tomato in 1992. The Flavr Savr was last grown in 1997. The Zeneca genetically engineered tomato was last grown in 1999.

Current Issues

Because genetically engineered tomatoes were not grown anywhere in the world as of 2006, there was not much controversy about them. Most arguments about genetic engineering were about corn and cotton, since genetically engineered varieties of those crops were being grown in large amounts.

Opponents of genetically engineered plants argue that genes from some genetically engineered crops might get into wild plants, with results that cannot be predicted or controlled. Most scientists do not think this is likely to do much harm. However, those scientists who study ecology—the ways in which living things, both plants and animals, affect each other when living together in communities—tend to have more doubts about genetic engineering than other kinds of scientists.

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[*See Also* **Vol. 2, Corn, Genetically Engineered; Vol. 3, Plant-Made Pharmaceuticals; Vol. 2, Rice, Genetically Engineered; Vol. 2, Soybeans, Genetically Engineered; Vol. 2, Transgenic Plants.**]

Transgenic Animals

Description

Scientists can change an animal's trait, for example making the animal more resistant to disease. They do this by adding a gene for the trait to the animal's genome (gene set). They get this gene from another organism of the same or of a different species. An animal whose genome has been changed by the addition of a foreign gene is called transgenic. That animal may be able to pass the new gene to its offspring.

Transgenic animals can be used as models to help scientists study disease. They can also produce more nutritious milk and meat to feed people, provide organs for transplant into humans, or produce substances in their milk that can help prevent or treat diseases.

Scientific Foundations

The nucleus of every animal cell contains deoxyribonucleic acid (DNA), the twisted ladder-shaped molecule of genetic information. DNA determines what an organism looks like and how its parts work. Genes are sections of DNA that contain recipes, or codes, for cells to produce proteins, which are substances that it uses to carry out most of its functions. Genes and the proteins they produce determine which traits an animal will have. The entire set of genes in an animal is called its genome.

Scientists can alter an animal's genes by finding and transferring the segment of DNA that codes for a particular trait from another organism. The DNA can come from the same or from a different species. When the new gene is introduced, it becomes incorporated into the animal's genome. The new gene leads to the production of specific proteins, which cause the animal to exhibit the

This chicken has been genetically modified to produce a human anti-cancer substance. When perfected, the technique may be used to produce cancer drugs. © *McPherson Colin/CORBIS SYGMA.*

desired trait. If the germ cells (sperm and egg cells, the animal's reproductive cells) also contain this gene, the animal should be able to pass the new trait to its offspring.

Development

For hundreds of years, farmers have selectively bred animals to give them certain traits, such as softer wool or more tender meat. But breeding is a very slow and imprecise process, and scientists wanted to be able to more quickly create animals with very specific traits.

They were helped along by the discovery of the molecular structure of DNA by American biologist James Watson (1928–) and English biologist Francis Crick (1916–2004) in 1953. In the 1960s, scientists discovered special types of proteins that can recognize and cut DNA at specific sequences of bases. These proteins, called restriction enzymes, allow scientists to separate out exactly which gene they want to use.

In 1973, American biochemists Herbert Boyer (1936–) and Stanley Cohen (1935–) developed recombinant DNA technology. This is a technique for cutting apart and splicing (putting together) DNA from different sources. Their method allowed genes to be

Supermice and Knockout Mice

In 1982, Ralph Brinster of the University of Pennsylvania and Richard Palmiter of the University of Washington inserted a rat growth hormone gene into mouse embryos. Their experiment produced ''supermice'' that were twice as big as normal mice. Transgenic mice are still used to study diseases and their potential treatments because they are genetically similar to humans and are easy to work with in a lab. Scientists not only can add genes to mice, but they can also disrupt the function of the mouse's own genes. Mice that have had a gene disrupted in this way are called knockout mice. Knockout mice help scientists model genetically based human diseases.

transplanted from one species to another. The first transgenic animals—mice—were born in the early 1980s. Within a few years, scientists also had created transgenic rabbits, sheep, cattle, and pigs.

To create a transgenic animal, scientists must first find the gene in the same species or in another species related to the trait they want, for example, disease resistance or more nutrient-rich meat. They then use restriction enzymes to separate that gene from the rest of the DNA. They duplicate the gene in the laboratory. Then they insert the gene into the new animal.

There are several ways to transfer the new gene into the animal's cells. One method is called microinjection. The new gene is injected into a newly fertilized egg. Then the cell is coaxed to develop into an embryo (an animal in the earliest stages of development) in a laboratory. Finally, that embryo is implanted into a female of the same species. However, this process is not very efficient. There is a chance that the new DNA will not insert itself into the gene of the embryo. If that happens, the animal will not have the desired trait.

Another way to transfer the new gene is by a type of inactivated virus (a tiny organism that can multiply in its host's cells). The virus infects the animal's cell, transferring the new gene to it.

In another method, called nuclear transfer, scientists remove the nucleus of an unfertilized egg and replace it with the nucleus from a donor cell that has the desired gene. An electric current is used to get the egg to begin dividing. Once it becomes an embryo, it is implanted into a female.

Words to Know

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Embryo: A stage in development after fertilization.

Enzyme: A protein that helps control the rate or speed of chemical reactions in the cell.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Genome: A complete set of the DNA for a species.

Germ cell: A cell that can pass its DNA on to future generations, including egg and sperm cells.

Nuclear transfer: Transfer of the central portion of living cells (those that contain a nucleus) that contains the genetic material. Bacteria and viruses do not have a nucleus.

Recombinant DNA: DNA that is cut using specific enzymes so that a gene or DNA sequence can be inserted.

Restriction enzyme: A special type of protein that can recognize and cut DNA at certain sequences of bases to help scientists separate out a specific gene.

Transgenic: A genetically engineered animal or plant that contains genes from another species.

Virus: A very simple microorganism, much smaller than bacteria, that enters and multiplies within cells. Viruses often exchange or transfer their genetic material (DNA or RNA) to cells and can cause diseases such as chickenpox, hepatitis, measles, and mumps.

Current Issues

Some people believe that transgenic animals offer the promise of a more plentiful and nutritious food supply, could increase the supply of organs for people who need transplants, provide medicines in their milk, and help scientists study and learn how to treat diseases. But those who are against the practice worry that the altered genes might mistakenly get into the wild animal population. For example, a transgenic fish could mate with a wild fish and pass along the new gene, with unknown results. There is also concern about the safety of eating food that has been genetically modified. For example, if a cow were altered with a gene from a peanut, a person with a peanut allergy who drank its milk might become very sick.

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[*See Also* **Vol. 2, Animal Cloning; Vol. 3, Animal Research and Testing; Vol. 2, Breeding, Selective; Vol. 2, Genetically Modified Organisms; Vol. 2, Recombinant DNA technology; Vol. 1, Xenotransplantation.**]

Transgenic Plants

Description

A transgenic plant is one that has had its DNA (deoxyribonucleic acid, its genetic information) changed in a laboratory. Transgenic plants are also called genetically engineered or genetically modified plants. Transgenic animals and microorganisms (living things too small to see with the naked eye) also have been created.

Transgenic plants have been given genes from other plants or from completely different kinds of organisms, such as animals or bacteria. A gene is a short section of DNA that tells a cell how to do a particular job. The purpose of these transferred genes, or transgenes, as they are called, is to change the character of the plant by changing what its cells can do. Transgenic plants have been engineered for many traits or characteristics.

Herbicide resistance. A herbicide is a chemical that kills plants, usually weeds. Many farmers and gardeners spray herbicides on their fields to kill weeds, so that the plants they want to grow don't have to share soil, light, and water with the weeds. Many plants have been genetically engineered to withstand large amounts of herbicides, so that farmers can kill more weeds without hurting crops.

Pest resistance. In farming, pests are insects or other organisms that eat crops. Several species of plants, including corn, cotton, and alfalfa, have been genetically engineered to make an insecticide or insect-killing chemical in their leaves and other tissues. The chemical is called Bt because the gene that codes for it comes from a bacterium called *Bacillus thuringiensis*. The plants that have been engineered to make Bt are called Bt crops.

The transgenic melon on the right has been genetically modified to stay fresh longer than the non-modified melon on the left. © *PHOTOTAKE.*

Disease resistance. Some crops, including squash and potatoes, have been genetically engineered to withstand some of the viruses that can infect them.

Stress tolerance. In biology, a stress is anything that makes it more difficult for an organism to live or grow. Too much or too little water, too much heat or cold, or too much salt are some stresses that can affect crops. Some transgenic plants have been genetically engineered to withstand these stresses.

Biopharmaceuticals. A pharmaceutical is a medicine, drug, or vaccine. Some crops, including corn and rice, have been genetically engineered to make medicines in their seed, leaves, or other parts. Usually, making a drug requires expensive machinery and skilled chemists; with transgenic plants, a drug could be made in large amounts simply by growing, harvesting, and processing a crop.

Crop quality. The number of other traits that scientists have added to transgenic plants, or would like to add to them, is large. In the late 1990s, transgenic tomatoes were created that ripened more slowly than normal tomatoes. These tomatoes were supposed to taste better and reduce special treatments costs for ordinary tomatoes. They have not been grown since 1999, however, because the idea did not make money. Transgenic crops that contain extra vitamins, make larger seeds or fruit, or have other desirable qualities also have been made.

Scientific Foundations

DNA is short for deoxyribonucleic acid. Almost every cell in a plant or animal has a complete set of the DNA molecules for that organism. The DNA molecule in cells is shaped like a long, twisted ladder with anywhere from a few rungs to billions of rungs. The rungs make genes (short sections of DNA that have a complete meaning). Thousands of genes are strung together to make up a whole DNA molecule.

When an organism makes offspring, its DNA is copied and passed on to the next generation. The DNA tells the cells of the growing plant or animal how to behave and so shapes the whole organism. In this way, DNA acts like a blueprint for the plant or animal. Even in the adult, DNA keeps working. Every cell consults its DNA like a book of recipes for making the molecules it needs to live and do its job.

To make a transgenic organism, scientists change the blueprint. To do this, they must first read the genetic code, and decide which genes they want to change. Then they must copy those genes and add them to the DNA of some plant, animal, or microorganism. This can be done using viruses that change the DNA of the cells they infect, or by shooting the genes into the cells using a special tool called a gene gun.

Development

Transgenic plants could not be created until scientists understood the nature of the DNA molecule and knew how to change it. The structure of DNA was discovered in 1953 by American biologist James Watson (1928–) and English biologist Francis Crick (1916–2004). Chemicals called restriction enzymes, which allowed biologists to cut DNA molecules at chosen points, were discovered in 1970. By the late 1970s, all the tools and know-how were in place to create transgenic organisms.

The first transgenic plant to be grown in open fields was tobacco, in 1986. Since the late 1980s, many transgenic varieties of tomatoes, corn, cotton, and many other crops have been created. As of 2006, about 70 percent of transgenic cropland was planted in herbicide-resistant plants—mostly Roundup Ready® transgenic plants (which are resistant to Roundup® brand herbicide). Almost

Europe 0, United States 1 . . . Sort Of

Europeans have been much more suspicious of food from transgenic plants than have Americans. As of 2004, about 86 percent of European citizens did not think transgenic food was safe. As a result, many European countries have banned the import or growing of transgenic crops. In 2003, the United States filed a complaint with the World Trade Organization (WTO) to protest the European rejection of transgenic food. In 2006, the WTO ruled in favor of the United States, saying that the European Union was wrong on several legal points. European countries were quick to point out that they were still free, by international law, to ban transgenic foods if they wished. Since most European consumers would refuse to buy transgenic foods anyway, market forces will probably continue to keep such foods out of European supermarkets, no matter what is decided by governments or the WTO.

all of the remaining 30 percent of transgenic cropland was planted in pest-resistant crops, especially Bt cotton and Bt corn. Most of the corn and cotton being grown in the United States today is transgenic.

Not many acres have been planted with virus-resistant or other forms of transgenic crops. Only a few test fields have been planted with transgenic plants designed to make pharmaceuticals or other chemicals for industry.

Current Issues

There is intense disagreement about whether it is wise to grow transgenic plants. Most scientists and government officials believe that there is no reason to fear transgenic plants and that such plants can help the world in many ways. Some scientists and many—in some countries, most—non-scientists disagree. They believe that transgenic plants are a danger to other kinds of crops, to ecosystems (communities of plants, animals, birds, and other living things), to the ability of small farmers to make a living, and possibly to human health.

Feelings run high over genetic engineering. Some people dislike the thought that scientists are meddling with their food and are not comforted by being told that it is for their own good. But opposition to transgenic crops goes far beyond mere dislike. There are questions about whether traditional crop varieties will be lost, whether viruses will pick up genes from transgenic crops, whether genes from transgenic crops will pollute wild species and other crops, whether human health might be hurt, and more.

Words to Know

Gene gun:	A device that shoots tiny metal bullets coated with DNA fragments into cells in order to alter their DNA permanently.
Herbicide:	A chemical substance used to kill weeds or undesirable plants.
Insecticide:	A chemical that kills insects. Used in agriculture to kill insects that eat crops.
Microorganism:	An organism too small to be seen without a microscope, such as a virus or bacterium.
Pharmaceutical:	A drug, medicine, or vaccine.
Transgenic:	A genetically engineered animal or plant that contains genes from another species.

Supporters of genetic engineering say that there is not enough scientific evidence to justify these worries. They argue that transgenic plants can benefit many people and that opposing them is unreasonable and destructive. These plants have not been proven dangerous, they say.

But neither have they been proven safe, their opponents reply. And the debate goes on.

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[*See Also* **Vol. 2, Genetic Pollution; Vol. 3, Plant-Made Pharmaceuticals; Vol. 2, Terminator Technology.**]

Vegetable Oils

Description

Vegetable oils are extracted from plants. Certain parts of plants, typically seeds, contain large amounts of fats that are used to produce vegetable oils. Groundnut, sunflower, mustard, olive, corn, palm, and sesame are some examples of plants used to produce vegetable oils. Some oils, like castor oil, require specialized processing before humans can consume them.

Some vegetable oils, such as olive, sesame, groundnut, corn, and sunflower oils, are widely used in cooking. In addition, vegetable oils are used extensively in industry, including food processing and the manufacture of such products as soaps, cosmetics, candles, perfumes, creams, ointments, and lubricants.

Vegetable oils are also known to have medicinal value. Used in aromatherapy and massage therapy, such oils relieve body aches and soften rough skin. Warm mustard oil helps to open blocked noses, helping people with sinus problems. Clove oil is commonly used for toothaches. Almond oil is rich in vitamin E and helps promote health. Other oils are a good source of antioxidants (chemicals that may reduce rates of cancer and heart disease), beneficial fatty acids, and minerals.

Scientific Foundations

Plants use seeds to produce new plants. Seeds not only contain the genetic material to create a new plant, but also essential nutrients and fatty acids to nourish the new plant until its roots are established in the ground. These fatty acids stored in seeds are extracted and used as vegetable oils. Other plant parts, such as flowers, bark, leaves, and even roots, can also be used to produce oils. For example, the peels of citrus fruits contain large amounts of oil.

This used restaurant vegetable oil will be used to power a Volkswagon truck, which has been converted to run on vegetable oil instead of gasoline. © *Mike Kepka/ San Francisco Chronicle/ Corbis.*

A vegetable oil may consist of saturated fatty acids or unsaturated fatty acids. Saturated fatty acids have the maximum amount of hydrogen a fatty acid can contain. Hydrogen saturation makes it easier for the body to densely store these fats. On the other hand, unsaturated fatty acids cannot be packed as tightly in the body. As a result, they are stored in smaller amounts and are a healthier food choice.

Development

Humans have used vegetable oils for a wide variety of purposes since ancient times. The Egyptians, for example, used oils for aromatherapy, ritual ceremonies, and mummifying members of the royal family after death. In ancient Greece, olive oil—referred to as liquid gold—was used as a medicine, cosmetic, and food. Blended with oils from other plants, olive oil was used to prepare creams. The use of oils gradually spread from Egypt to other parts of the world, including China, India, and the Middle East.

Although vegetable oils had been used since antiquity, people did not understand their chemical properties. In 1809, French

Biodiesel Facts

Biodiesel is produced from any fat or oil by a refining process called transesterification. This process removes glycerin from the oil to produce biodiesel by reacting the oil with an alcohol. Biodiesel can be used as a fuel all by itself or it can be blended with petroleum in any percentage. Annual sales of biodiesel in the United States are increasing rapidly. In 1999, only about 500,000 gallons (1.9 million liters) were sold, but by 2005, sales had increased to 75 million gallons (285 million liters).

chemist Michel-Eugène Chevreul (1786–1889) began to study soaps made from animal fat. Eventually, he successfully identified and named several fatty acids. In 1816, he also confirmed Scheele's discovery of the presence of alcohol in plant and animal fat.

During the twentieth century, soybean oil became the preferred vegetable oil in the United States. Researchers in Canada in the mid-1970s discovered the benefits of an oil derived from a variety of mustard—called rape—and started marketing it as canola oil. Vegetable oils became a preferred medium for cooking, since they are inexpensive and are considered healthier than animal fats.

Cooking was not the only use of vegetable oils. Beginning in the nineteenth century, automotives and other petroleum-based products were invented, but the limited nature of the supply of fossil fuels led scientists and engineers to search for alternative fuels. The inventor of the diesel engine, German engineer Rudolf Diesel (1858–1913) demonstrated that peanut oil is a viable fuel for vehicles in the late 1800s. However, his designs received little attention and most motor vehicles continued to use petroleum-based fuels.

By the 1970s, there was a renewed realization that the supply of fossil fuels would one day run out, and scientists began to focus their research on renewable fuel sources, such as plants. This led to the development of renewable fuels, such as biodiesel. In addition to being a cost-effective replacement for petroleum, biodiesel reduces pollution from motor vehicles, lubricates engines better than other fuels, and, most importantly, is a renewable fuel. Vegetables oils, especially soybean and rapeseed oils, are a key component of biodiesel. Also, previously used vegetable oil that is easily available from the food industry can be converted into biodiesel, thus transforming a waste material into fuel.

Words to Know

Algae: A group of aquatic plants (including seaweed and pond scum) with chlorophyll and colored pigments.

Biodiesel: An environmentally friendly fuel made from a combination of plant and animal fat. It can be safely mixed with petro diesel.

Diesel engine: An internal combustion engine that burns diesel oil as fuel.

Fatty acid: An acid made of carbon, hydrogen, and oxygen that is found in body fat.

Oil: Animal or vegetable fats that are liquid at room temperature.

Current Issues

The advantages of biodiesel have prompted many countries to switch, at least partially, to this fuel and to develop policies to increase its use. Today, different countries use different oils to produce biodiesel. For example, the United States primarily uses soybean oil to make biodiesel, while Germany uses rapeseed and Brazil uses sunflower seeds, soybeans, or castor beans.

However, biodiesel also has certain drawbacks. Although it promises to be an attractive replacement for petroleum, vast agricultural lands are required to grow the crops needed to produce enough oil to meet the ever-growing demand for fuel. Extensive farming may necessitate an increased use of pesticides, herbicides, and fertilizers, raising concern among some individuals about the true environmental impact of producing biodiesel.

In addition, switching completely to biodiesel may not be practical because most agricultural land is used to grow food crops. In countries where people struggle to get enough to eat, converting land from producing food to producing oil plants for biodiesel production could compromise the amount of food available to feed the population.

Research is being conducted to develop plant varieties with high oil content. Further, experiments are being conducted to extract oil from oil-rich varieties of algae (tiny plant-like organisms that live in water). Compared to plants, algae are simpler in structure, easier to grow, and yield far more oil than any other plant.

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[*See Also* **Vol. 3, Oil-Seed Crops.**]

Stalks of a genetically modified wheat plant. *Adam Hart-Davis/Photo Researchers, Inc.*

Wheat, Genetically Engineered

Description

Wheat is a grass whose seeds are used as food. It is the second most widely grown crop in the world, after corn and ahead of rice. Genetically engineered wheat (also known as genetically modified wheat or transgenic wheat) is wheat whose DNA has been changed in the laboratory.

Like most food crops, there are many varieties of wheat, each with different traits. A few varieties of wheat have been genetically modified for the same reasons that many other food crops have been genetically modified. Cotton, corn, soybeans, rice, tomatoes, bananas, and many other plants have all been genetically changed to make them resistant to chemicals or insects, or to make them produce medicines or other useful substances.

As of 2006, no genetically engineered wheat was being grown anywhere in the world.

Scientific Foundations

Genetic engineering means changing the DNA of a plant or animal in the laboratory. Deoxyribonucleic acid (DNA for short) is a long, tape-like molecule found in all living cells. DNA contains information written in a chemical code. Almost every cell contains a complete copy of all the DNA that a plant or animal has. Creatures use the information in DNA to make their offspring, and most cells also use their DNA as a recipe book that tells them how to make all the molecules they need during their life.

For thousands of years, people have noticed the natural changes that happen in each new generation of plants and animals. These changes are largely caused by differences in DNA. By breeding new generations from individual plants and animals that showed desirable changes, such as producing more milk or bigger seeds, people have used natural DNA changes to make plant and animal varieties that are more useful than wild ones. Genetic engineering has the same goal but changes DNA in a single generation using technology rather than working with naturally occurring changes in DNA.

A gene is a short section of DNA that tells a cell how to make a certain substance or do some other job. New traits or features are added to plants by adding genes to a few new cells from a different organism and then raising new plants (clones) from the changed cells. Seed can then be harvested from the adult clones. A gene can be added to a plant's DNA by several methods. One is to shoot many copies of the gene into the cell using a device called a gene gun. Scientists take tiny particles of metal, paint them with copies of the gene, and fire them through cells using a gene gun. Some of the new DNA stays in the cell and gets added to the cell's own DNA.

Development

The Monsanto Company, which is based in the United States, has developed more kinds of genetically engineered plants than any other group. In 1982, Monsanto scientists were the first in the world to genetically modify plant cells. In 1987, they were the first to test genetically modified crop plants in open fields. During the

Secret Amber Waves of Grain

Some persons are in favor of genetic engineering of plants. Others oppose the idea. Feelings run high in this debate. So heated has it become that when Monsanto was growing its test fields of Roundup Ready wheat in 2003, it kept the location of the fields secret. ''It is for the cooperative researcher's safety, the facilities and crop,'' said Michael Doane, director of industry affairs for Monsanto. Since the late 1990s, in California, England, and France, foes of genetic engineering have repeatedly destroyed experimental fields of genetically modified plants by trampling them underfoot—literally trying to stamp out genetic engineering.

1990s, Monsanto developed and began selling genetically modified varieties of rice, soybeans, corn, and other plants. Much of the corn, cotton, and soybeans grown in the United States consists of genetically modified varieties from Monsanto.

Monsanto began development of genetically engineered wheat in 1997. The wheat was engineered to resist a chemical called glyphosate. Glyphosate is an herbicide, a chemical that kills plants. Farmers use herbicides to kill weeds so that crops can grow better. If the wheat, cotton, or corn in a field is genetically engineered to resist glyphosate, then more glyphosate can be sprayed on the field, killing more weeds without hurting the crop.

Most glyphosate is sold by the Monsanto Company under the brand name Roundup®. Monsanto develops glyphosate-resistant genetically engineered crops (what it calls Roundup Ready varieties) so that it can make money first by selling genetically engineered seed to farmers and then by selling them the Roundup to spray on the crops they grow from that seed. Farmers who buy these seeds hope to make more money by raising crops with fewer weeds.

Current Issues

Although Monsanto has been successful in selling its Roundup Ready corn, cotton, soybeans, and canola, it has failed with Roundup Ready wheat. In May, 2003, after growing test fields of its Roundup Ready wheat in North Dakota and Canada, Monsanto announced that it was not going to try selling the wheat after all.

The main reason for Monsanto's decision was that most of the buyers of the U.S.-grown wheat of the kind that Monsanto had genetically engineered (known as hard red spring wheat) are against the idea of genetically engineered foods, and would certainly refuse to buy

Words to Know

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Gene gun: A device that shoots tiny metal bullets coated with DNA fragments into cells in order to alter their DNA permanently.

Glyphosate: A weed-killing chemical; the world's most-used herbicide.

Herbicide: A chemical substance used to kill weeds or undesirable plants.

bread made with genetically engineered wheat. American farmers said that they would not buy Roundup Ready wheat because they were afraid they would not be able to sell their crop to foreign buyers. In their minds, it simply was not worth the risk. If too few customers want to buy a product, there is no point in trying to sell it, so Monsanto gave up on genetically engineered wheat.

Another company, Syngenta, has also developed a second kind of genetically engineered wheat. Syngenta's wheat is resistant not to glyphosate but to a kind of fungus called *Fusarium* that infects wheat. However, the same problem that kept Monsanto from selling its Roundup Ready wheat has kept Syngenta from trying to sell its *Fusarium*-resistant wheat: lack of demand.

As of 2006, no company was seeking government permission to sell genetically engineered wheat.

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[*See Also* **Vol. 2, Corn, Genetically Engineered; Vol. 2, Genetic Engineering; Vol. 2, Genetic Pollution; Vol. 1, Genetically Modified Foods; Vol. 2, Rice, Genetically Engineered; Vol. 2, Transgenic Plants.**]

Wine-Making

Description

Wine is an alcoholic beverage. Like beer, it is made using the fermentation process, in which yeast converts the plant's sugar to alcohol. But unlike beer, which is made by fermenting grains, wine is made by fermenting grapes. Wine has been in existence for thousands of years, and it has become an important part of human rituals and culture.

Scientific Foundations

Fermentation is a process by which a single-celled type of fungus called yeast is used to break down glucose (a type of sugar molecule) to produce carbon dioxide gas and ethanol (the alcohol in wine). Carbon dioxide is the main part of the air that humans and animals exhale, and it is the gas that is put into sodas to make them fizzy. Special chemicals called enzymes in the yeast break the glucose down in a process called glycolysis when there is no oxgen in the surrounding air. Glycolysis produces a substance that provides the yeast with energy, with carbon dioxide and ethanol as leftover waste products.

Development

Even though the fermentation process was not well understood at the time, wine-making dates back to 6,000 BCE. The first wines were produced in Mesopotamia (modern-day Iraq) and Caucasia (a region in Eurasia). The ancient Egyptians buried their dead with vessels filled with wine in order to ensure a happy afterlife. They also painted scenes of wine-making on tomb walls. Over time, wine-making spread throughout Europe and eventually made its way to the Americas.

ANTIGUA BODEGA GIOL
LA NOCHE DEL VINO
1993

Large casks used to ferment wine in Argentina. © *Susan D. Rock.*

In 1863, the French chemist Louis Pasteur (1822–1895) discovered that yeast was responsible for wine fermentation. Once winemakers understood that yeast converted grape sugars into alcohol and carbon dioxide, they were able to gain more control over the fermentation process.

Producing wine starts with grapes. The grapes are picked from the vines and taken to a winery, which is a place where wine is made. The grapes are placed in a machine called a crusher. As the machine crushes the grapes, the juice and skin exit through holes in the drum. The juice and skin are called the must. Next, if a white wine is being made, it is taken to a wine press, which separates the juice from the skin. Red wine is made using both the skin and juice. Grape juice is white, whether it comes from a red grape or a white grape. Leaving in the skin during the fermentation process gives red wine its color.

The grape juice then goes to fermentation tanks. The winemaker adds yeast to the grape juice. The type of yeast that is used can change the flavor of the wine. The yeast converts the sugars in

Making Champagne

Champagne is a sparkling wine. It starts out, just like wine, with the fermentation of grapes. But to give champagne its carbonation, wine-makers ferment it a second time. They do this by adding extra yeast and sugar when they bottle the wine. The extra carbon dioxide that is produced during this fermentation becomes trapped in the bottle, giving champagne its bubbles. Then the bottle is slowly turned upside down and rotated a little bit each day. This process, called riddling, causes the dead yeast to rise into the neck of the bottle. The neck of the bottle is frozen and the small piece of ice containing the dead yeast and sediment (solid particles that have settled in the bottom of a liquid) are removed. Then the bottle is corked again.

the grape juice into carbon dioxide gas and alcohol. How long the wine is left to ferment, and therefore how much sugar is left in the wine, determines how sweet it will be. If all the sugar is fermented, the wine is said to be dry. The fermentation process can take several weeks. The carbon dioxide that is created during fermentation is allowed to escape, so the wine does not become bubbly. After fermentation, red wines are sent to a press to remove the skins. Both red and white wines are filtered to remove the yeast left during the fermentation process.

The next step is to store the wine in stainless steel vats or oak barrels. The wine-maker adds a type of bacterium (a tiny, one-celled organism) to the wine. The bacteria break down a strong naturally occurring chemical and make the wine less strong and sour, and more mild and sweet. The wine sits in the vats or barrels (called aging) for anywhere from a few months to several years. How long the wine is aged also affects the taste. Then it is bottled.

Current Issues

The growing demand for new and unique varieties of wine has led wine-makers to introduce more advanced wine-making methods. They use improved fermentation techniques, as well as more high-tech equipment. But there is another, more controversial method for improving wine quality. Some wine-makers are altering the DNA (deoxyribonucleic acid, the molecule in cells that carries the genetic information) of yeast to change the way it reacts with sugars during the fermentation process. Genetically modified yeast has been used to remove certain flavors, for example, which would otherwise give the wine a bad taste. Genetically modified yeast also can help rid the

Words to Know

Bacteria: Microscopic organisms whose activities range from the development of disease to fermentation.

Carbon dioxide: A heavy, colorless gas that dissolves in water.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Enzyme: A protein that helps control the rate or speed of chemical reactions in the cell.

Fermentation: The process of breaking down sugar without oxygen into simpler substances, commonly alcohol and carbon dioxide.

Glucose: A simple sugar that exists in plant and animal tissue. When it occurs in blood, it is known as blood sugar.

Glycolysis: A set of reactions in living organisms that use sugars and produce ATP, a molecule that provides cellular energy.

Yeast: A microorganism of the fungus family that promotes alcoholic fermentation, and is also used as a leavening (an agent that makes dough rise) in baking.

wine of bacteria, which could spoil the wine. However, many winemakers do not want consumers to know that their wine has been genetically modified. This is because wine-making is seen as an old and respected tradition and because many consumers are wary about genetically modified foods. They worry that these foods could have potentially harmful effects on their health.

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[*See Also* **Vol. 2, Beer-Making; Vol. 2, Bread-Making; Vol. 3, Ethanol; Vol. 3, Fermentation, Industrial; Vol. 3, Yeast Artificial Chromosome.**]

Yogurt-Making

Description

The manufacture of yogurt is a biotechnology process that is centuries old. The deliberate fermentation of milk by certain types of bacteria has been practiced for more than four thousand years. Bacteria are tiny organisms can be found in nearly every environment. Some can cause disease, but many species are beneficial.

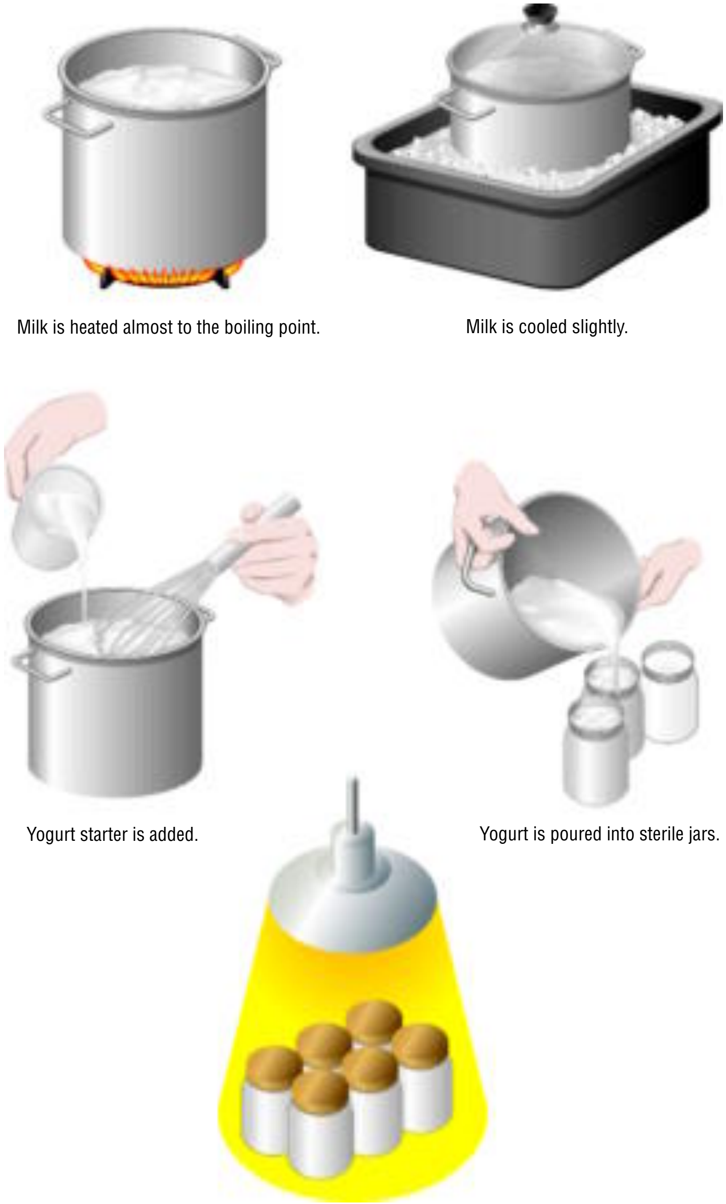
The types of bacteria traditionally used in yogurt are *Lactobacillus delbrueckii* subspecies *bulgaricus* and *Streptococcus salivarius* subspecies *thermophilus*. Today, yogurt can also contain *Bifidobacteria* and *Lactobacillus casei*, which do not take part directly in the fermentation but which contribute to the health benefits of the milk product.

Yogurt is an example of a probiotic—bacteria-containing food that, when eaten, helps prevent unwanted bacterial from growing in the intestinal tract. A steady diet of yogurt is beneficial, because the living bacteria that are eaten can attach to the intestinal wall and grow, helping the person digest food more effectively. If yogurt consumption is stopped, the bacteria are soon out-competed by the other bacterial constituents of the intestine.

Scientific Foundations

Bacterial fermentation of milk involves the conversion of a milk sugar called fructose into lactic acid. This makes the mixture more acidic and changes the character of the milk. Instead of a liquid, the fermented milk becomes gel-like and acquires a sharper taste. Many do not think this taste is pleasing, so to make yogurt taste better it is often flavored with fruit, vanilla extract, and even chocolate.

How yogurt is made



Milk is heated almost to the boiling point.

Milk is cooled slightly.

Yogurt starter is added.

Yogurt is poured into sterile jars.

Yogurt is kept warm to incubate bacteria
culture for about 12 hours.

Yogurt-making is a process that can be carried out at home using store-bought yogurt as a starter culture. *Illustration by GGS Inc.*

Yogurt Goes Mainstream

Only a few decades ago, yogurt was viewed as an exotic and not necessarily desired food. Then, fewer than 10 percent of Americans ate yogurt regularly. In 2005, that figure had jumped to more than 20 percent of the population. During that year, sales of yogurt surpassing $3 billion, an increase of seven percent from 2004, according to the market research firm A.C. Nielsen. Yogurt is now added to items as different as cereal, granola bars, baby formulation, pet food, and even toothpaste.

Yogurt preparation relies on the presence of bacteria. Centuries ago, this likely happened as a the result of the accidental contamination of the milk. However, people realized the value of this accident and stored milk in conditions that were helpful to bacterial growth. As the process became more refined, the role of the specific bacteria mentioned above became recognized. Modern-day yogurt preparation involves the deliberate introduction to the milk of a mixture that usually contains both bacterial species. This mixture is called the starter culture.

Yogurt can be made using either of the bacteria alone, but the process occurs more quickly when both types are present. This is because the presence of each type of bacteria helps the other to grow. The streptococci are able to become established in the milk and grow more quickly than the lactobacilli. This produces carbon dioxide (the gas that makes soda bubbly) and an acidic compound called formate. In turn, the lactobacilli use the carbon dioxide and formate as nutrients. Growth of the lactobacilli frees nutrients that can be used by the streptococci for their renewed growth.

The growth and metabolism (the process by which food is broken down) of the bacteria changes the character of the milk. As the milk becomes more acidic, milk proteins change their three-dimensional shape. This process is called coagulation. As a consequence, the milk becomes gel-like in texture. The texture can be maintained by the addition of substances such as pectin or gelatin (both are thickeners). Some yogurt formulations also include a preservative, to extend the shelf life of the product.

Plain yogurt (yogurt that does not contain added ingredients such as fruit) can be made in two ways. In the stirred style, the bacteria are evenly dispensed in the milk and yogurt formation is allowed to occur, after which the product is packaged for sale. In the set style, the yogurt is packaged for sale right after the starter

Words to Know

Fermentation: The process of breaking down sugar without oxygen into simpler substances, commonly alcohol and carbon dioxide.

***Lactobacillus*:** Bacteria that create lactic acid.

culture has been added to the milk. The bacterial action occurs as the product goes to the marketplace.

The second style has gained popularity during the 1990s, because it makes sure that the yogurt will contain live bacteria when eaten. Research has established that regular consumption of such yogurt can have health benefits, because the bacteria in the yogurt can attach to and live on the walls of the intestinal tract. This can prevent harmful bacteria from living in the intestines and causing illness.

In addition to these helpful bacteria, yogurt is a good source of several B vitamins and minerals. As well, it can be digested by people who are lactose intolerant (and so who cannot drink regular milk without suffering intestinal pains).

Development

While yogurt-making is centuries old, the commercial process was refined during the 1990s. Then, as the health benefits of probiotics became clearer, yogurt manufacturers began to deliberately market yogurt in which the bacteria were still alive.

Something else happened because of the popular acceptance of yogurt as a food, even as a snack food. The design of processes that removed moisture from the yogurt without affecting its flavor or texture caused the development of a yogurt paste. The paste could be applied to other foods, such as granola bars, to produce a product that people might like better.

In response to demand, the development of new flavors of yogurt continues, as does the development and improvement of yogurt-containing food products.

Current Issues

The most important current issue concerning yogurt-making is making more consumer items that contain yogurt. As developed societies age and people continue to take an interest in their own health, consumer demand for healthy foods and probiotics will increase.

The basis of yogurt-making is not likely to change significantly. While it is possible that genetically modified bacteria could ease the process of yogurt production, reducing the cost of producing the product in commercially relevant quantities, the public may well disapprove of this approach.

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[*See Also* **Vol. 2, Cheese-Making; Vol. 3, Fermentation, Industrial.**]

Biotechnology

Changing Life Through Science

Biotechnology

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Volume 3
Industry

K. Lee Lerner and
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Amino Acids, Commercial Use

Description

Amino acids are the chemical building blocks of the human body. Proteins are the substances that make up all living cells and their components, and proteins are made of chains of amino acid molecules. As amino acids are one of the basic molecules in the body, they find widespread industrial uses, many of which mimic nature. Consequently, several amino acids are used in consumer foods, beverages, health enhancers, drugs, and animal feed.

There are many different amino acids. One, glutamic acid, is used in the commercial industry as AuxiGro®—a chemical used to enhance the growth of vegetables, fruits, and nuts. Another common use of amino acids is in the production of aspartame, the key component of artificial sweeteners available under brand names such as Equal®. Apart from being used as a sugar substitute, aspartame is found in soft drinks, processed foods, and vitamin supplements. Aspartame is about 180 times sweeter than regular sugar without adding significant calories.

Moreover, since amino acids function as neurotransmitters (chemical messengers between nerve cells) to facilitate communication within the nervous system, they are the key ingredients in drugs produced for treating brain-related abnormalities such as depression, anxiety, panic attacks, sleep disorders, and eating problems like obesity.

Scientific Foundations

Amino acids are basic molecules that connect to each other to form elaborate chains. Considered the building blocks of proteins in the body, amino acids can be found in the blood, muscles, ligaments, body fluids, hair, and everything else made up of proteins.

Our bodies produce most of the amino acids required for daily upkeep. However, some amino acids must be obtained from our food intake as the body is unable to produce them. Such amino acids are called essential amino acids. The human body uses twenty amino acids of which nine are essential. Other amino acids that the body can produce by itself are called non-essential amino acids. Although they are called non-essential, the body does need them as much as it does the essential amino acids.

Development

The amino acid industry was born in the beginning of the twentieth century, soon after people discovered the flavor enhancing properties of glutamic acid. Subsequently, the importance of adding amino acids to animal feed was discovered. Chemical synthesis of the essential amino acid methionine, formulated in the 1950s, facilitated production of amino acid rich feed for livestock. Also in the 1950s, Swedish scientist and Nobel Laureate Arvid Carlsson (1923–) showed that levodopa, a chemical derived from the amino acid tyrosine, brings relief to animals with symptoms of Parkinson's disease—a nervous system disorder.

In 1965, a chemist accidentally discovered the sweet taste of aspartame while working on making a drug for treating ulcers. However, it was only in 1981 that the U.S. Food and Drug Administration (FDA) approved aspartame for commercial production in certain foods.

By the 1980s, other amino acids, including lysine, tryptophan, and threonine, had also been chemically synthesized (created in a laboratory). These amino acids are used in animal feed production for the food and dairy industry.

Several other commercial uses of various amino acids were soon discovered. Research showed that the human body, for activities requiring muscle power, uses proteins and amino acids as sources of energy. This discovery gave birth to the health food and medicine industry that actively started marketing protein and amino acid supplements in the form of energy-boosting drinks, power bars, tablets, and capsules. These products are targeted at bodybuilders, fitness-conscious people, weight lifters, and others engaged in extensive physical workouts.

Importance of a Protein-Rich Diet

Amino acid supplements can be taken to meet the body's requirements. However, the human body absorbs proteins more easily than amino acids. Taking amino acid supplements without consulting a doctor may cause harm to the body. Considering the importance of amino acids, having a protein-rich diet is important for a healthy body.

Current Issues

Ever since aspartame was discovered as a sweetener, its consumption has been highly controversial. Laboratory experiments to study the effects of aspartame have at times resulted in the occurrence of brain cancer in rats, though the cause of cancer is not known. Research carried out to study its effects in humans has been inconclusive. It is well established that aspartame is harmful for people with phenylketonuria (PKU), a genetic disorder causing mental retardation and brain damage.

Protein-rich animal feed causes animals to excrete increased amounts nitrogen in their urine and feces, leading to soil and water pollution. An economical way of reducing this pollution is to feed the animal a diet low in proteins but high in amino acids. Recent studies have shown that even a small reduction in proteins and increase in amino acids is remarkable in lowering nitrogen pollution. Another advantage is that a low-protein, high-amino acid diet does not affect meat quality.

Aside from the controversies, many amino acids are extensively used commercially, especially in the flourishing health-food industry. An essential amino acid, isoleucine, is used in the body for hemoglobin (the oxygen-containing part of red blood cells) formation, blood clot formation, and blood sugar regulation. Along with two other amino acids, valine and leucine, isoleucine heals muscles after strenuous physical activity. These properties have fueled the availability of isoleucine supplements.

Meat is one of the foods most consumed by humans. Considered a complete protein (containing essential and non-essential amino acids) compared to plant protein, meat is further improved by feeding a protein and amino acid-rich diet to animals. It is for this reason that amino acids are also used to make

Words to Know

Aspartame:	A low calorie artificial (synthetic) sweetener.
Essential acid:	Acids that cannot be synthesized by the body and must be obtained from the diet.
Metabolism:	The physical and chemical processes that produce and maintain a living organism, including the breakdown of substances to provide energy for the organism.
Neurotransmitters:	Biochemical substances that transmit nerve impulses between nerve cells.

nutrient-rich feed for livestock. Commercial availability of several amino acids has further enhanced the process of producing enriched animal feed.

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[*See Also* **Vol. 1, Collagen Replacement; Vol. 1, DNA Sequencing; Vol. 1, Protein Therapies.**]

Animal Research and Testing

Description

Scientists often use animals as research models for human diseases and treatments. Animals make good research models because their genetic makeup can be very similar to that of humans; they have the same organs (lung, liver, heart); and they get many of the same diseases as humans get.

Researchers test medicines, vaccines, and other possible treatments on animals. A vaccine is a substance made of a killed or weakened virus or other disease-causing agent, which protects the body against the disease. Animal testing can help scientists learn which dose will work best and what side effects the drug might have before testing it on humans. Other products can be tested on animals, as well. For example, a cosmetics company might test out a new perfume on rabbits, to make sure that it will not cause injury if sprayed into the eyes.

Not all research conducted on animals is for the purpose of studying human treatments. Much of it focuses on the animals themselves—how much and what types of foods they eat, what factors make them likely to develop certain diseases, and what types of medicines might best be used to treat those diseases. This research helps scientists keep pets and livestock healthier and protect endangered species.

There are several ways to create disease models and test potential treatments on animals. One is to simply give the animals a drug or product to see how well it works. The other involves genetically modifying the animals to mimic the genetic changes seen in certain human diseases.

A scientist takes blood from a sedated rat, which is being used to research the Ebola virus in Africa. Ebola causes severe blood loss and has a high fatality rate. © *Patrick Robert/Sygma/Corbis.*

Scientific Foundations

All animals contain deoxyribonucleic acid (DNA), the double-stranded chain of genetic information that is held in the nucleus of every cell. The cell's nucleus is a structure that controls most of its functions. DNA is made up of four chemical bases: guanine (G), thymine (T), cytosine (C), and adenine (A). Genes are sequences of these bases that form a code, telling cells how to make specific proteins. Proteins are the main components of living things, and take part in how a cell functions. The entire set of genes in an animal is called its genome. Changes called mutations that occur to certain genes can cause disease.

Scientists can study a disease by genetically modifying an animal so that it will develop that disease. They alter an animal's gene by finding and transferring the segment of DNA that codes for the disease from another organism. Copies of that gene are usually injected into a fertilized egg so that they become a part of the animal's genome. The DNA can come from the same species or from a different species. An animal that has received DNA from another organism is called transgenic.

Development

In the nineteenth and twentieth centuries, animals helped scientists discover the pathways of disease, and the techniques needed to perform organ transplants and other surgical procedures. For example, in 1908, two doctors named Karl Landsteiner (1868–1943) and Erwin Popper injected monkeys with extracts of polio taken from a boy who had died of the disease. Polio is a serious disease that in its most severe form causes paralysis of the legs, arms, and respiratory (breathing) system. This animal model helped them identify the virus that caused the disease and helped lead to the future development of a polio vaccine, which was done by American doctor Jonas Salk (1914–1995), in the 1950s.

During the 1920s, Canadian researchers Frederick Banting (1891–1941) and Charles Best (1899–1978) found that injecting an extract made from cells of the pancreas (an organ that produces the hormone insulin) into a dog that had diabetes relieved its symptoms. Diabetes is a disease in which the body does not produce enough of the hormone insulin (or does not use insulin properly) and so cannot regulate blood sugar levels. The substance in those cells that helped the dog get better was called insulin, and it soon became a very important diabetes treatment for humans.

In the 1950s, researchers such as American surgeon Joseph Murray (1919–) used animals to help them perfect kidney transplant techniques. Heart transplants were first attempted in dogs during the 1960s. Many other medical techniques were first attempted on animals before being tried on humans too.

Rats and mice are the most common animals used for research. Rabbits, guinea pigs, hamsters, and fish are also used. Animal research is broken down into several different areas. Researchers use animals to test new surgical techniques and vaccines for diseases in both humans and animals. They also use them to learn how tissues and cells in the human body stay healthy. Scientists can test new medicines on animals to find out exactly how they affect the organs, and whether they might be harmful. They can also use animals to test other products, such as perfume, sunscreen, and bug spray, to make sure they will not cause any health problems when humans use them.

Today, animals (especially mice and rats) are often used in genetic experiments. These experiments help scientists discover the function of a certain gene, or model how a disease works.

Animals and Kidney Transplants

As with many other areas of medical research, the first organ transplants were done using animals to see if the techniques worked before trying them out on humans. A French researcher named Alexis Carrel (1973–1944) used cats and dogs to develop a method of joining blood vessels. This method was needed to successfully transplant organs from one person to another. Then Carrel tried transplanting organs from one animal to another. These experiments helped him identify the problem of organ rejection—an immune response in which the body attacks foreign tissue that has been introduced into it. American surgeon Joseph Murray perfected kidney transplants in dogs before he tried the surgery for the first time on humans in 1954. Animals also have helped scientists perfect many other types of organ transplants. They have also helped researchers test the drugs needed to prevent organ rejection.

Scientists can alter an animal's genes to make that animal develop a certain disease, such as cystic fibrosis, a genetic disorder that causes mucus (phlegm) to build up in the lungs, making breathing difficult. They can do this by finding and transferring the segment of DNA that codes for that disease from another organism of the same species or of a different species.

Scientists not only can add genes to animals, but they also can disrupt the function of genes. They can genetically modify mice so that they lack a certain gene. These modified mice are called knockout mice. By seeing what happens when a gene is missing, scientists can better understand how that gene works.

Current Issues

Many animal rights groups have protested that animal testing is cruel and inhumane. But researchers say they need to perform these tests to ensure the safety of treatments for humans. And they say they take steps to protect the animals they use. For example, before they test a new drug on animals, researchers try it out on isolated cells and tissues. Today, many researchers are trying to find alternative methods for testing, such as computer models, that do not involve animals.

Words to Know

Cystic fibrosis: A fatal disease in which a single defective gene prevents the body from making a protein, cystic fibrosis transmembrane conductance regulator.

Diabetes: A disease in which the body cannot make or properly use the hormone, insulin.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Genome: A complete set of the DNA for a species.

Insulin: A substance made by the body (or by genetically engineered bacteria) that the body needs to regulate the amount of sugar in the blood.

Mutation: A change in a gene’s DNA. Whether a mutation is harmful is determined by the effect on the product for which the gene codes.

Polio: A disease (poliomyelitis) caused by a virus that can result in muscle weakness, paralysis, or death.

Rejection: An event that occurs when the body’ss defense (immune) system attacks a transplanted organ.

Toxic: Something that is poisonous and that can cause illness or death.

Transgenic: A genetically engineered animal or plant that contains genes from another species.

Vaccine: A product that produces immunity by inducing the body to form antibodies against a particular agent. Usually made from dead or weakened bacteria or viruses, vaccines cause an immune system response that makes the person immune to (safe from) a certain disease.

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[*See Also* **Vol. 2, Animal Cloning; Vol. 1, Anti-Rejection Drugs; Vol. 1, Blood-Clotting Factors; Vol. 3, Cosmetics; Vol. 1, Cystic Fibrosis Drugs; Vol. 1, Organ Transplants; Vol. 2, Transgenic Animals; Vol. 1, Xenotransplantation.**]

Antimicrobial Soaps

Description

Antimicrobial soap is a cleaning product that contains chemicals that fight germs. Ordinary soap cleans by breaking up dirt stuck to the skin. Antimicrobial soaps work the same way, but they also reduce or kill bacteria. Such soaps are commonly called antibacterial soaps. They do not kill viruses. Most germ-killing soaps sold for home use contain the chemical triclosan or the chemical triclocarban.

Antibacterial soaps are often used in hospitals and physician's offices to help keep infections from spreading. They are also sold in stores. In 2001, the majority of liquid soaps sold in stores contained antibacterial ingredients and about 29 percent of bar soaps contained germ-killing chemicals.

Scientific Foundations

Doctors say that washing hands with soap and warm water is one of the most important, and easiest, ways to keep dangerous germs from spreading. Hand-washing with regular soap removes some bacteria from the skin, but bacteria quickly return. Antimicrobial soaps are a way to further reduce the chance of disease by killing bacteria that can lead to infection. Antibacterial soap leaves a germ-killing agent on the skin that continues to work even after hands are dried. Tests show that fewer germs remain on the skin after washing with antibacterial soap than after washing with regular soap. It takes two minutes for antibacterial soap to work completely, so it is important to wash hands thoroughly before rinsing.

Antibacterial soaps are recommended for people who frequently come in contact with diseases that can be spread. Studies have shown that antibacterial soaps reduce bacterial infections caused

Doctors preparing for surgery use strong antibacterial soaps to kill germs on their hands. *Sotiris Zafeiris/Photo Researchers, Inc.*

by *Staphylococcus aureus* (Staph) and *Streptococcus* (Strep). Strep throat is a common sickness caused by *Streptococcus*. Some physicians also suggest that children with certain skin conditions such as acne or impetigo (a common skin infection that causes crusty sores) use antibacterial soap to control these conditions.

Development

Soap has been around for thousands of years. The Greek physician Galen (129–c. 199) said people should wash with soap to clean their skin and prevent disease. Soaps made to keep germs from spreading have been sold since the 1920s. In 1948, a meat-producing company called Armour introduced Dial®, the world's first soap specifically labeled as being antibacterial. Dial came in bar form, and within six years it was the top-selling soap in the United States. In the late 1980s, the company introduced Dial antibacterial liquid hand soap. Within just ten weeks, the company sold one million dollars' worth of the new soap.

By the 1990s, the public's interest in antibacterial products intensified, and a number of other companies started producing

How Clean Are We?

The American Society for Microbiology and the Soap and Detergent Association commissioned a study to compare how often Americans say they wash their hands versus how often they do actually wash them. A telephone survey asked participants whether or not they washed their hands after performing a variety of activities. Observers then recorded whether individuals using the bathroom in public places washed their hands afterwards. Here is the summary of their findings:

- Ninety–eight percent of people say they always wash their hands after using the bathroom. The number observed doing so is eighty–three percent.
- From the four cities observed, Atlanta, Chicago, New York, and San Francisco, the dirtiest hands were found in Atlanta.
- In the observations, ninety percent of women wash their hands versus seventy–five percent of men.
- People said they were most likely to wash their hands after using the bathroom (eighty–three percent), before cooking or eating (seventy–seven percent), and after changing a diaper (seventy–three percent). They were least likely to wash their hands after sneezing, coughing, or petting a dog or cat.

antibacterial soaps. Since the year 2000, at least 1,500 new antibacterial products have been made available to the general public.

Current Issues

Whether antibacterial soaps are safe and effective is a matter of debate. A study published in a 2004 medical journal found that those who used antibacterial cleaners got symptoms of colds and stomach infections as often as those who did not use them. Colds and many stomach problems are caused by viruses, which cannot be killed with antibacterial soaps. In October 2005, the U.S. Food and Drug Administration (FDA) said that antibacterial soaps are no better than ordinary soap. The agency made the decision after a vote of twenty to one.

One of the main arguments against antibacterial soaps is that they also kill the good bacteria that live on the skin. Some bacteria actually help protect the body against illness from other, more dangerous germs. Because of this, some people think that antibacterial soaps will make bad bacteria become stronger, leading to "super germs" that can not be killed by antibiotic medicines. This is called bacterial resistance. The FDA has also warned that the chemicals in antibacterial soaps might build up in groundwater

Words to Know

Antibacterial: A substance that reduces or kill germs (bacteria and other microorganisms but not including viruses). Also often a term used to describe a drug used to treat bacterial infections.

Antibiotic: A compound produced by a microorganism that kills other microorganisms or retards their growth. Genes for antibiotic resistance are used as markers to indicate that successful gene transfer has occurred.

Antimicrobial: A material that slow the growth of bacteria or that is able to to kill bacteria. Includes antibiotics (which can be used inside the body) and disinfectants (which can only be used outside the body).

Bacterial resistance: Immunity evolved by a certain strain of bacteria to one or more antibiotics.

Triclocarban: A chemical that kills bacteria.

Triclosan: A chemical that kills bacteria. Most antibacterial soaps use this chemical.

and dirt. This could contaminate drinking water and foods grown in soil, and further raises the threat of resistant bacteria. The link between antibacterial soaps and bacterial resistance is just a theory. But some say the risk is too great, and antibacterial soaps should not be sold if they do not work. The American Medical Association has encouraged the FDA to take a closer look at antibacterial products and possibly control their availability.

The soap industry insists that antibacterial soaps work better than ordinary soap and do not increase the risk for bacterial resistance. Instead, it says overuse of antibiotics is to blame for the problem. In 1997, experts from the soap industry presented studies to the FDA that said there was no link between bacterial resistance and the use of antibacterial soaps.

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[*See Also* **Vol. 1, Antibiotics, Biosynthesized; Vol. 2, Soap-Making.**]

Biodegradable Packaging and Products

Description

Biodegradable objects decompose naturally due to or assisted by biological organisms. Solid waste that is biodegradable is desirable, since breaking it down will reduce the volume occupied by the waste in a landfill.

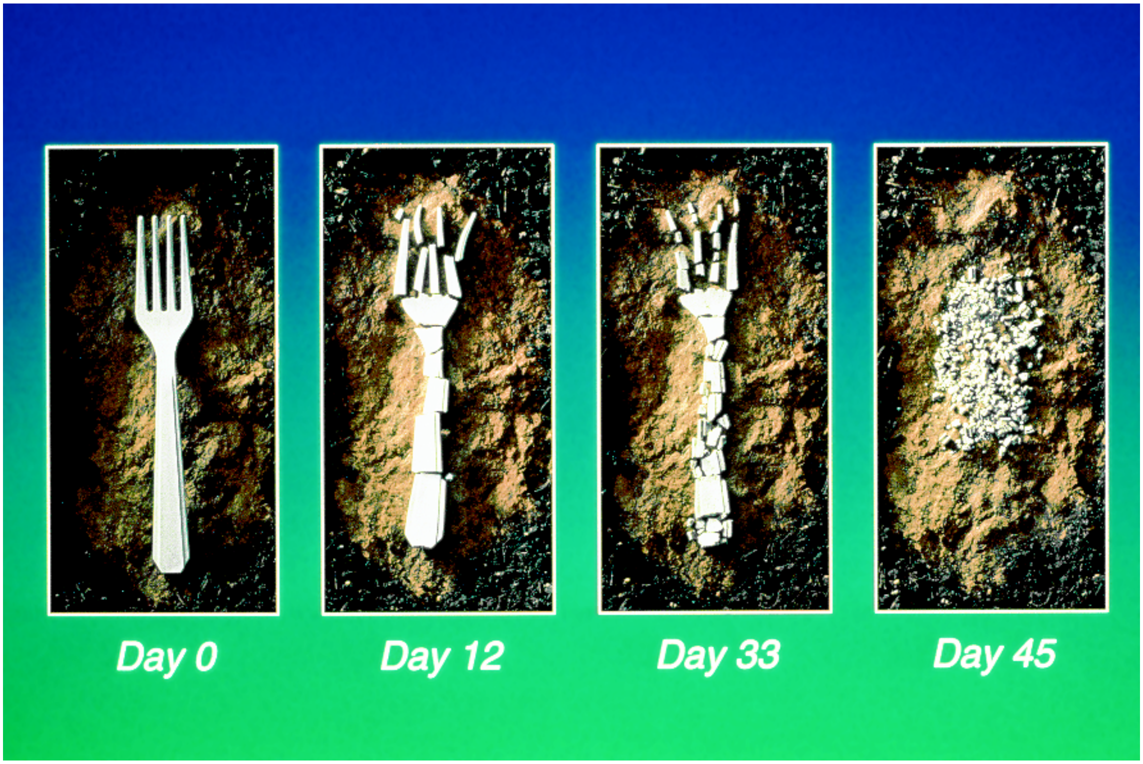
A well-known example of biodegradation is composting, where organic (carbon-containing) material is broken down by certain types of bacteria to yield simpler compounds (combinations of atoms). This breakdown releases energy that can be used by the bacteria (one-celled germs that exist almost everywhere on Earth) for growth and reproduction.

Biodegradable packaging material exists and is increasingly being used. In addition, some types of products made of plastic and other materials are biodegradable. As with the composting process, biodegradation of commercial products and packaging is beneficial to the bacteria associated with the process.

Scientific Foundations

Microorganisms (tiny living things that too small to be seen without a microscope) are able to decompose a material when they can use enzymes to break chemical bonds in that material. Enzymes are biological compounds that speed up the rates of chemical reactions. Packaging materials and even some products themselves can be made of materials that can be broken down by the enzymatic activity of microorganisms that are commonly found in the soil.

Packaging material can contain polylactic acid, which is a starch-like material that is derived from corn. Reflecting this



Biodegradable forks made from corn-based plastic. They decompose in 45 days. © *Robert Ressmeyer/ CORBIS.*

origin, one manufacturer has dubbed the package a "corn-tainer." This material can be made flexible, and so it can be used to make bags. More rigid packaging can also be made. Versions of the material that are derived from wheat, sugarcane, and potatoes are also available.

Plastics that can be used in both packaging and the manufacturing of products are derived from petrochemicals (chemicals derived from crude oil). Some types of naturally occurring bacteria, particularly *Pseudomonas aeruginosa*, can use petroleum as a food source. (This bacterium was used in the aftermath of the *Exxon Valdez* oil spill to clean polluted shorelines in Alaska.)

Traditional packaging material is made of a polymer called polyethylene terephthalate. (A polymer is a very large molecule in which one or two small units are repeated over and over again.) The compound, which is popularly referred to as polyester and is widely used in the manufacture of food and drink containers, is virtually non-degradable. This is because the polymer structure is ring-shaped, and the bonds in chemical rings are not broken by enzymes.

153A
172 B5
172 B4
172 B3
171 B2
172 B1
177 F3
177 A2
113 A1
113A3

Biodegradable meat packaging made from wheat. *© Vo Trung Dung/CORBIS SYGMA.*

In the presence of oxygen, biodegradable packaging/product materials can be broken down within weeks. Decomposition takes longer in a landfill, since there is less oxygen present. The anaerobic (without oxygen) bacteria found in the reduced or oxygen-free environment of a landfill tend to grow more slowly than their oxygen-loving (aerobic) counterparts.

Like any decomposition process, complete biodegradation yields carbon dioxide gas, water, and whatever small amount of

Replace Those Landfills with Compost Piles

Some scientists envision a future in which landfills are replaced with compost piles for waste disposal. A key ingredient in this greener future is the use of fully biodegradable composites for everything from car interiors and computers to packaging materials and consumer products. These composites would be made of fibers from plants—such as ramie (an Asian plant that produces a fiber similar to flax or silk), kenaf (an African fiber plant related to cotton), pineapple, or banana—embedded in a resin of soybean protein or another biodegradable plastic. And not only would these materials be environmentally friendly because they naturally biodegrade in compost piles, but they are also made from renewable agricultural resources rather than non-renewable petroleum. Perhaps, one day landfills will be a thing of the past.

material that cannot be broken down. Because carbon dioxide is produced, landfills need to be designed to vent this gas.

Development

Some biodegradable materials require a combination of conditions before decomposition can occur. One example is a material called Totally Degradable Plastic Additive, which is made and sold by a company based in Vancouver, British Columbia, Canada. The material requires oxygen, moisture, and the appropriate microorganisms; decomposition is triggered by sunlight, heat, or some mechanical stress. An Australian company has developed a cornstarch-based product that begins to decompose within a hour after exposure to water. These additives can be incorporated into conventional plastic packaging material to make the formerly degradation-resistant material susceptible to breakdown. Virtually any type of packaging material can be made.

The development of biodegradable packaging materials and products continues to be driven by the approval of the items for sale. As of 2006, a wide variety of packaging materials and products had been approved and marketed globally including:

- Biodegradable food bags and wraps
- Garbage bags
- Bowls, dishes, and other serving containers
- Water bottles
- Furniture, such as benches and picnic tables.

Words to Know

Biodegradable: Able to be broken down by natural processes.

Compost: A mixture of decaying organic matter, such as manure and leaves that can be used as fertilizer.

Enzyme: A protein that helps control the rate or speed of chemical reactions in the cell.

Genetic engineering: The manipulation of genetic material to produce specific results in an organism.

Plastics: A group of natural or synthetic polymers that are capable of being softened and molded by heat and pressure; also sometimes used to include other structural materials, films, and fibers.

Polymer: A chemical compound formed by the combination of many smaller units.

In another avenue of development, the enzymes that are active in the biodegradation process are also being studied. This research seeks to better understand the conditions that could increase and prolong enzyme activity. In addition, the tools of genetic engineering are being applied to improve enzyme performance.

Current Issues

The annual market for biodegradable packaging has already reach $25 billion, and the demand continues to grow. The German-based company BASF predicts that from 2005 to 2010 the world market for plastics that are biodegradable will grow by 20 percent each year.

As of 2006, biodegradable plastics were a small proportion of the total volume of packaging/product materials that are used. However, this is changing. In 2005, the Sam's Club division of Wal-Mart began using biodegradable wrapping for fresh produce in the United States. McDonald's now uses packaging made of a mixture of limestone and potato starch.

In addition, government legislation is driving the expanded use of biodegradable materials. For example, Ireland has imposed a tax on items packaged in bags that are non-decomposing. As a result, Irish consumers have a financial incentive to buy items packaged in degradable material. In another example, in 2005 the German Packaging Ordinance was revised to exempt manufacturers from paying tax on biopackaging materials.

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[*See Also* **Vol. 3, Bioplastics; Vol. 3, Cornstarch Packing Materials.**]

Biodetectors

Description

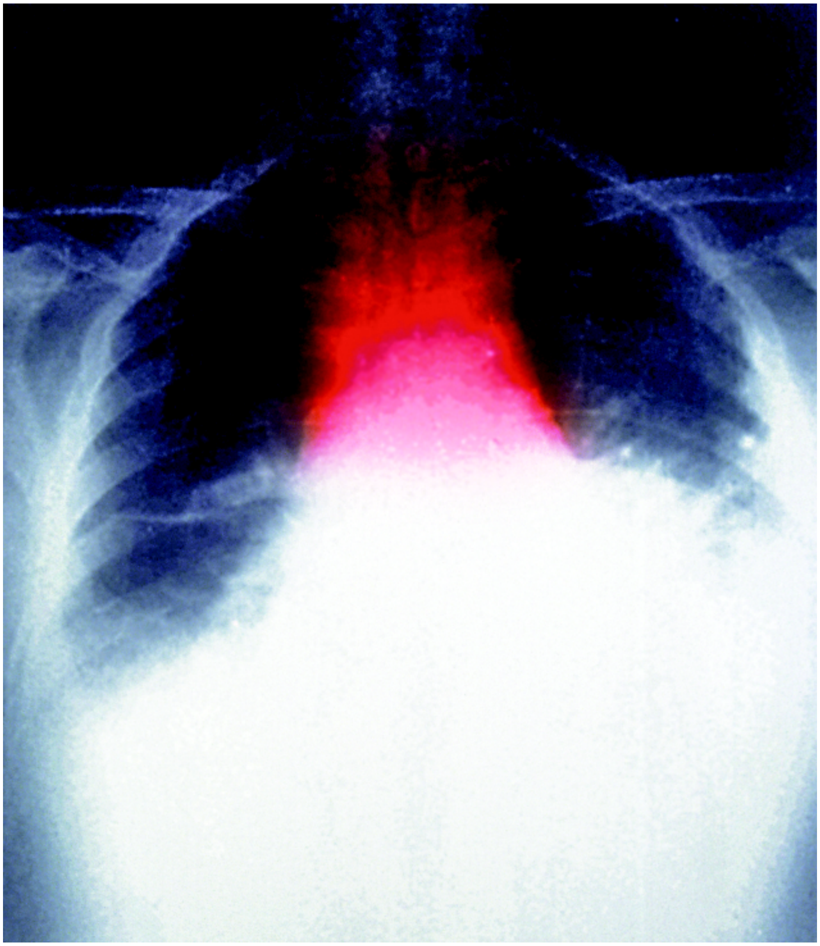
Biodetectors are devices that are designed to sense the presence of biological material. Depending on the detector and its design, the target can be complete microorganisms such as bacteria, or parts of the microorganisms. (Microorganisms are living things too small to be seen without a microscope, such as bacteria.) These parts, which can reveal the presence of microorganisms that are no longer alive, are useful in the forensic analysis of a crime scene and in the examination of tissues from a deceased person.

One type of biodetector is called an immunosensor. When the body's immune system detects foreign matter, it identifies an antigen (a substance associated with the foreign material) and produces a specific antibody to destroy it. An immunosensor uses antibodies to detect the presence of the related antigen to which they have been formed.

The usefulness of biodetectors to rapidly detect the presence of deliberately released microorganisms has become increasingly important since the series of incidents in the United States in the fall of 2001, in which letters contaminated with an environmentally hardy form of *Bacillus anthracis*—the bacterium that causes anthrax—were sent through the mail to various people. The knowledge that such bioterrorism can be conducted this easily has made development and routine use of biosensors a national security priority.

Scientific Foundations

Biodetectors combine the detection sensitivity and precision of biological tests with the ability of a machine to process data. The result is a machine that can detect the presence of small numbers



Colored x ray of anthrax inhalation. The red area shows where the anthrax bacteria was taken into the lungs. Biodetectors could detect such airborne germs and send up an early alarm to minimize exposure. *Scott Camazine/Photo Researchers, Inc.*

of microorganisms. For example, some biodetectors are able to find a single living bacterium in a volume of 100 milliliters, which compares to a ping-pong ball put into an Olympic-sized swimming pool. The detection of bacterial components or various toxins can be in the range of micrograms (a microgram is one millionth of a gram) or nanograms (one billionth of a gram) of the component per milliliter.

The detection of a microorganism or a component can occur in different ways. Air biodetectors can be equipped with a suction pump that samples the air. The incoming air is passed through a tiny opening that is monitored by a beam of light. Breaking of the light path by a particle is detected and can be used to determine how many particles are in the air. While this design does not distinguish living from dead objects, it can be useful, because the

BioWatch

BioWatch is a program initiated by the U.S. Department of Homeland Security. Biosensors located in more than thirty major cities in the continental United States suction in air and deposit any particulates on a filter. Subsequently, the filters are retrieved and taken to laboratories for analysis.

The system costs approximately $2 million annually for each city, mainly due to the labor involved in the manual retrieval and transport of the filters. The ongoing installation of wireless biosensors will enable data to be set directly to the remote analysis facility.

Also, BioWatch is expanding to include the monitoring of the inside of buildings of concern such as government facilities. A similar biodetector system called the Remote Data Relay is being used by the U.S. Department of Defense to monitor military installations.

presence of a high number of particles in the air can be an indicator of the possible presence of microorganisms. This biodetector has the advantages of being relatively inexpensive and easy to operate.

In a modification of this principle, biodetectors exist that detect DNA. DNA (deoxyribonucleic acid) is the part of almost every living cell that contains hereditary information. DNA biodetectors are based on the ability of the genetic material to bridge the gap between two electrodes (electrodes collect electric charge), permitting the flow of electricity. Thus, detection of an electric current is evidence of the presence of DNA.

More precise detection and counting of microorganisms relies on the use of biodetectors using proteins that are immobilized on a surface. Proteins are the substances that make up most of the matter of living cells. The proteins on a biodetector recognize and bind (attach to) the microorganim. This is the basis of the antibody-based immunosensor. The bound part or whole microorganism can then be detected and measured based on other tests. Another biodetector design immobilizes deoxyribonucleic acid (DNA) on a surface. The DNA can be adjusted to bind only to the DNA sequence of target regions of the microorganisms' genetic material.

Development

Biodetectors have been modified to incorporate wireless technology. Similar to the technology employed for computers, this allows data collected by a biosensor to be relayed automatically to a central facility for storage and analysis.

Words to Know

Anthrax: A deadly disease caused by anthrax bacteria. Used more often as a biological weapon than any other bacterium or virus.

Biodetectors: Devices that can detect biological molecules and substances.

Bioterrorism: Terrorism using biological weapons such as bacteria or viruses.

Immunosensor: Drugs or radiation used to reduce the immune system's ability to function.

Another biodetector contains a surface that is uneven. The surface texture allows several bacteria to be entrapped within a fluid-filled pore. This enables the bacteria to survive for a time following their detection, so they may be recovered and further analyzed.

Yet another biodetector design relies on the odors given off by metabolic processes to detect microorganisms. Thus far, this device has been explored for agricultural purposes, for example, to detect the presence of the disease-causing type of bacteria called *Escherichia coli*, or *E. coli*, on produce such as apples.

Promising new designs of biosensors continue to be developed, including one capable of simultaneously detecting more than one hundred toxins (poisons), viruses, and bacteria.

Current Issues

Biosensors are becoming smaller, more sensitive, and less prone to damage. Pocket-sized portable biosensors capable of detecting the bacteria that causes anthrax have been developed and were tested during the Iraq war of 2003. Not yet in routine use, the biosensors will someday become part of a soldier's standard battlefield gear in conflicts where the use of biological weapons is possible.

In the new age of bioterrorism following the September 2001 terrorist attacks on the United States, the biosensors market has increased. Only two years after the 2001 attacks, biosensor sales in the United States had surpassed $7 billion. By 2007, biosensor sales may top $10 billion annually.

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[*See Also* **Vol. 3, Biological Weapons; Vol. 3, Security-Related Biotechnology.**]

Bioglass

Description

Bioglass® is a clear material made of calcium, phosphorous, silicon, and sodium salts. It is bioactive, meaning that it reacts to living things. Bioglass® is a type of artificially made glass classified as a bioceramic. It chemically reacts with body fluids to form a bond (attach) at the surfaces of tissues and bones. The elements that make up Bioglass® are needed to repair and grow tissues and bones. When seen under a microscope, a particle of Bioglass® looks like a piece of sand and is the size of a grain of table salt. The invention of Bioglass® led to the field of bioactive materials. Bioglass® is commercially sold by the Florida-based company NovaBone Products.

Bioglass® is called an osteoconductive material—a substance that gives structural support (what is called scaffolding) for cells to grow. It is also an osteostimulative, which means that growth occurs not just on the edge of the bond, but throughout the bond. Because of these two characteristics, Bioglass® helps the body repair damaged cells and grow new ones. As soon as Bioglass® is added to a damaged area, a chemical reaction between it and the body's fluids begins, so natural healing can occur.

The name Bioglass® comes from its *bio*active nature (its ability to interact with living organisms) and its silica (the material that makes glass) content. American ceramics engineer Larry Hench (1938–) invented Bioglass® at the University of Florida, which became the first artificially made material that was able to bond to tissues and bones.

Scientific Foundations

The term bioceramic is important to the function of Bioglass®. It is a general term that involves any ceramic (inorganic, non-metallic)

What do Boing-Boing! the Bionic Cat and Bioglass® Have in Common?

Boing-Boing! the Bionic Cat and Bioglass® were both invented by Larry Hench. The ceramics professor created Bioglass® in the 1960s. Boing-Boing! is the title character of a recent children's book written by Hench. He wanted to read a book to his grandchildren that taught science in a fun and interesting way but was still realistic (and not like a fairytale). Hench also wanted to find a book that described scientists as caring and helpful people, not as bad or absent-minded. He was unable to find one, so he decided to write his own children's book. Hench's story is about Daniel, a boy who loves cats but is allergic to them. Daniel meets Professor George who builds him a bionic cat made mostly of ceramics, with fiber-optic fur, sensor activated whiskers, computer controlled joints, and electronic eyes. Hench tells an interesting and realistic story about a problem that is solved using science and engineering.

material made artificially for use inside the human body as implants (artificially inserted devices) or prostheses (external, artificial body parts). There are three categories of bioceramics: inert, resorbable, and bioactive. Inert ceramics are used as a supporting surface. For example, it might be used for a hip joint. Resorbable bioceramics are any bioceramic material that dissolves after natural tissues are able to function without it. Bioactive ceramics, which are trademarked as Bioglass®, are compositions that can be easily changed with respect to bioactivity and mechanical strength. For example, high bioactivity would mean that the material has low mechanical strength.

Development

In 1967, during the Vietnam War, Hench met a U.S. Army officer in charge of supplying mobile army surgical hospitals (MASHs) in Vietnam. The men discussed the amputation of soldiers' limbs. Although prosthetic (artificial) materials were commonly used to replace natural parts, they were often rejected by the body's natural defenses. The Army officer hoped Hench could come up with a better material to use.

Hench already knew that glass contained large amounts of calcium and phosphorous. He thought that a combination of glass and ceramics might not be rejected since calcium and phosphorous are already found in the body. Hench researched the reasons why the human body rejected foreign materials and the use of ceramics as a biomaterial. In 1968, Hench received funding from the U.S.

Words to Know

Bioactive:	An artificial material that has an effect on a natural, living organism, cell, or tissue.
Ceramic:	A hard, brittle substance produced by strongly heating a nonmetallic mineral or clay.
Elements:	Pure substances that can not be changed chemically into a simpler substance.
Glass:	A ceramic material consisting of a uniformly dispersed mixture of silica, soda ash, and lime; and often combined with metallic oxides.
Graft:	A transplanted tissue.
Inorganic:	Composed of minerals that are not derived from living plants and animals.
Prosthetic:	An articifial replacement for a lost limb or other body part. An artificial leg is a prosthesis, as is a replacement heart valve.
Regeneration:	The ability of an organism to reproduce completely from a part of another one.

Army Medical Research and Development Command. He discovered that some of his compositions bonded to living bone and tissue and slowly released small amounts of silica and calcium into the body. This caused genes to grow, which caused new bones to be formed. The composition that Hench invented was called 45S5 Bioglass® and was composed entirely of elements that naturally occurred in the body.

Current Issues

Bioglass® has been important to many different medical fields, including orthopedics (bones), dentistry (teeth), ENT (ear, nose, throat), and maxillo-facial-cranial (jaw, face, head) applications. Since 1994, it has been used as a material for filling in defects within bone grafts. Bioglass® devices are also used to repair defects throughout the skeletal system.

Sold in over forty countries, Bioglass® has been used in over one-half million surgical procedures. Bioglass® heals tissues without infections. There is no risk of disease or rejection since Bioglass® is made completely of elements found in the human body.

Bioglass® is sold under the brand names of PerioGlas®, NovaBone®, and NovaBone-C/M®. PerioGlas® is used by dentists and oral surgeons to fill in damaged bones and to grow tissues. It has become especially useful as a substitute for tissues lost to advanced periodontal disease. Thousands of teeth are saved each year with the use of PerioGlas®. NovaBone® and NovaBone-C/M® are used for bone regeneration in facial reconstruction, orthopedics, and spine surgery. In 2002, NovaBone® was approved by the FDA as the first synthetic bone grafting material for orthopedic purposes. It is osteoconductive, osteostimulative, and resorbable (dissolves when no longer needed by the body).

■ ■ ■

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[*See Also* **Vol. 1, Bone Marrow Transplant; Vol. 1, Bone Substitutes; Vol. 1, Synthetic Biology.**]

Bioleaching

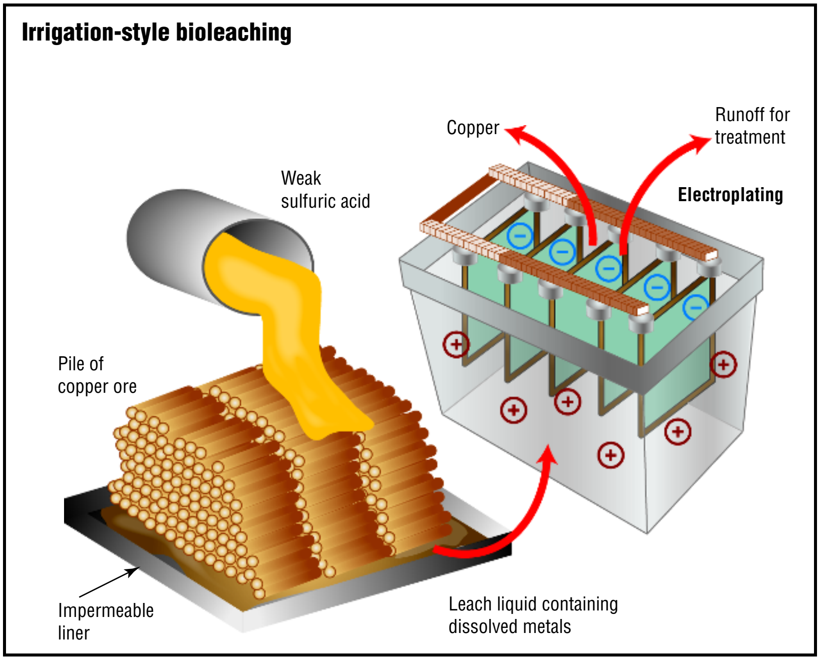
Description

Bioleaching is the process of taking out certain valuable metals with the use of bacteria, along with air and water. Bioleaching is used on sulfide ores, which are the naturally occurring rocks that contain valuable minerals along with sulfur. The bacteria used in the separating of metal sufides (sulfur-contain compounds) are usually *Thiobacillus ferrooxidans*, *Leptospirillum ferrooxidans*, *Thiobacillus thiooxidans*, and certain species of *Sulfobacillus*, *Acidianus*, and *Sulfolobus*. Bioleaching is often used in the mining industry to remove such metals as cobalt, copper, nickel, uranium, and zinc from their sulfide mineral ores when their concentrations are lower than normal or when other removal (extraction) methods are not as environmentally efficient or safe.

In bioleaching, metal is placed into a liquid solution while oxygen is added (a process called oxidation) so that almost all of the metal (usually 75 to 95 percent) can be separated from the other ore materials. The bacteria feed on the nutrients found in the sulfur part of the minerals. This oxidizing action by bacteria causes the metal to separate from the other materials. The metal is then collected in a solution. Once a large percentage of the metal builds up in the solution, it is filtered out.

Scientific Foundations

Bioleaching uses special microorganisms that act in a particular way on mineral deposits. They generally make the natural decaying processes of the ores go faster. The microorganisms increase the oxidation of iron sulfide crystals. In the case of copper bioleaching, sulfuric acid is produced through the oxidation process and


Irrigation-style bioleaching
Copper
Runoff for treatment
Electroplating
Weak sulfuric acid
Pile of copper ore
Impermeable liner
Leach liquid containing dissolved metals

In irrigation-style bioleaching, a chemical called sulfuric acid is poured onto a metal ore (in this case copper ore). The resulting liquid is processed through an electroplating device, which separates out the copper. *Illustration by GGS Inc.*

leaches out the copper. For uranium bioleaching, sulfuric acid leaches out the uranium.

Oxidation is a chemical reaction where an oxide is formed. An oxide is a compound composed of oxygen and another element. Oxidation is used to speed up reactions. For example, phosphorus mixes so quickly with oxygen that heat is given off in the reaction, which causes the phosphorus to burn.

Biooxidation is a process that is sometimes used interchangeably with bioleaching. The same bacteria used in bioleaching are used, but the metal, usually silver or gold, is left in its solid state. The solution is separated and removed.

Development

The development of bioleaching occurred mostly in Canada between the 1970s and 1980s. The removal of metals using bioleaching has since been developed in other countries. It is still being developed for use in colder climates. Currently, bioleaching is used only for valuable metals, such as copper and uranium. It has not been developed enough to make it a consistently useful technology for other metals such as cobalt, nickel, and zinc.

Copper bioleaching was first used in the Rio Tinto mine in Spain in the seventeenth century. However, only in the past few

Bio-prospecting in Hot Springs

Scientists have been exploring terrestrial and underwater hot springs to find naturally occurring microorganisms that can oxidize iron and sulfur compounds at higher temperatures of 158 to 185 degrees Farenheit (70 to 85 degrees Celcius). Such microorganisms allow bioleaching to proceed in faster and more efficient ways. The scientists are trying to determine the leaching capabilities of these microorganisms. Information they find tells them which microorganisms are able to leach out specific metals. The scientists hope their research results in more microorganisms suitable for the bioleach processing of various metals.

decades has it developed to a point that about eight to ten percent of the world's copper production is done by bioleaching. The first large-scale bioleaching of copper happened in the Lo Aguirre mine in Chile around 1980.

Current Issues

Bioleaching is used when other extraction methods are not acceptable. Such reasons include areas that are too far away and thus too expensive to mine using traditional methods. It is also used when other methods cause negative impacts to the environment. Bioleaching uses natural occurring microorganisms. It also uses less energy and does not produce as many dangerous emissions as do other methods.

Certain types of metal are not able to be efficiently extracted using bioleaching, making it too costly or too slow when compared to other extraction methods. However, in some developing countries other methods are not available because of lack of technology, materials, and money. Metals in these areas are removed with bioleaching because it is a relatively simple, effective, and low-cost method of metal extraction.

The process of bioleaching is being considered for the mining of metals on the moon and neighboring planets such as Mars.

Some problems do occur with bioleaching. It is a slower process than other extraction methods, which often makes it more costly to use. In some cases, the microorganisms are not easily controlled during the bioleaching process, which causes problems in removing the metal.

Another negative consequence of bioleaching is the production of dangerous metal-containing acids as byproducts of the leaching process. Bioleaching can also cause problems when mines are

Words to Know

Emissions: The generation of photons of light from an electronically excited atomic or molecular species in order to reduce its total energy.

Microorganism: An organism too small to be seen without a microscope, such as a virus or bacterium.

Oxidation: A biochemical process which is part of metabolism. It involves the steady but relatively slow release of energy from food molecules for cell activity.

closed and dangerous materials are allowed to leak into groundwater sources.

Bioleaching is part of the biotechnology industry. As a result, the federal government, primarily with the use of health and safety laws, regulates its operations. As of the 2000s, it is an emerging technology that has the potential to reduce overall processing costs for metal extraction companies, to be more environmentally friendly than conventional extraction methods, and to increase the amounts and percentages of recovered metals. Bioleaching produces less air and water pollution, damage to geological formations, and problems to the environment than other metal extraction methods.

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[*See Also* **Vol. 3, Enzymes, Industrial; Vol. 3, Government Regulations; Vol. 2, Soil-Modifying Bacteria.**]

Biological Weapons

Description

A biological weapon is any weapon that uses bacteria or viruses. Poisons collected from bacteria also can be used as biological weapons, but using larger living things as weapons—for instance, using trained dolphins to carry bombs underwater—does not.

Biological weapons can be used directly against people or against plants and animals that people depend on for food. The use of biological weapons is called biological warfare or germ warfare if it is done by a government, and it is called bioterrorism if it is done by a terrorist group.

Biological weapons are sometimes called "weapons of mass destruction," along with nuclear weapons (atomic bombs) and chemical weapons. However, these three kinds of weapons are very different. A single nuclear weapon, dropped on a large city, might kill millions of people instantly. Neither chemical weapons nor biological weapons are as dangerous as nuclear weapons. Chemical weapons have rarely been used in war, although poison gas was used with devastating effect in World War I (1914–18). A biological weapon has only been used once to kill large numbers of people—by Japan, during World War II (1939–45). Even then, it had little military effect, since the victims were random civilians. Most military experts agree that biological weapons will never be useful in war.

Biological weapons are poor weapons because they are hard to deliver to their targets. Germs sprayed from an airplane or released by a bomb must be carried by the air to the people (or crops or animals) that those germs are meant to harm. But, if the wind is not blowing the right way, the germs will not reach the targets.

New York firefighters and Marines wearing protective clothing in a simulated biochemical attack. © *Ramin Talaie/Corbis.*

Even if the wind is blowing the right way, it may change direction. Also, a biological weapon might backfire and injure the troops or civilians of the power using it. By their very nature, biological weapons are hard to control. Biological weapons are also too slow. A germ takes hours or days to kill a person after infection. Other people might take shelter in the meantime, or enemy military forces might strike back.

However, biological weapons could be useful for terrorism. Even without killing many people, they might cause panic and shut down a city for days or weeks. Biological weapons are scary because they are invisible. A person cannot know, at first, if he has been infected by the weapon, or how to keep from getting infected.

Scientific Foundations

Many bacteria and viruses cause disease naturally. To make a biological weapon, scientists breed germs found in nature to make

Anthrax Mystery

In 2001, about two weeks after the September 11 terrorist attacks, letters containing anthrax spores began arriving at the offices of two U.S. senators and several TV stations and newspapers. Anthrax is the kind of bacteria most commonly used for biological weapons. The anthrax spores infected twenty-two people and killed five. The cost of cleaning up postal-service buildings and other places contaminated by the anthrax was at least one billion dollars. Thousands of federal agents searched for the person or persons who committed these crimes, but, as of 2006, they had still not been found.

them more deadly. They may also change their deoxyribonucleic acid (DNA, the molecule used by all living things to pass on traits to their offspring). The most common germ used as a biological weapon is anthrax. Anthrax forms tiny, hard-to-kill spores like seeds. These spores are inactive until they enter an animal. Anthrax spores can be kept in a weapon for a long time and then sprayed in the air.

Development

People have thought of using biological weapons for many centuries. In the Middle Ages, armies attacking walled towns sometimes used machines called catapults to throw dead animals and people into the towns in hope of causing plague among the residents. In 1763, British general Jeffery Amherst ordered that blankets infected with smallpox be given to the Delaware Indians as a gift. Amherst hoped to cause an epidemic among the Indians. It is not known whether he succeeded.

During World War II, Japan experimented with biological weapons on thousands of Chinese prisoners. It also dropped plague-infected fleas on Chinese cities. These biological attacks may have killed several hundred thousand people. The United States built 500,000 bombs containing anthrax (the kind of bacteria most often used for biological weapons) during World War II, but never used them. The English Prime Minister, Winston Churchill, considered using these American anthrax bombs against German cities. He decided not to, however, because his advisors told him it would be cheaper and quicker to use fire bombs to set the cities on fire. This is what the British and American Air Forces did; between 570,000 and 800,000 German civilians were killed.

After World War II, both the United States and the Soviet Union built large stockpiles of biological weapons. In 1979, an accidental

Words to Know

Anthrax: A deadly disease caused by anthrax bacteria. Used more often as a biological weapon than any other bacterium or virus.

Biological and Toxic Weapons Convention: Treaty dating to the early 1970s that forbids the use of biological weapons.

Biological weapon: A weapon that uses bacteria, viruses, or poisonous substances made by bacteria or viruses.

Vaccine: A product that produces immunity by inducing the body to form antibodies against a particular agent. Usually made from dead or weakened bacteria or viruses, vaccines cause an immune system response that makes the person immune to (safe from) a certain disease.

release of anthrax spores from a weapons factory in Russia killed more than 100 people. However, in the 1960s, the United States urged the world to ban biological weapons. In 1972, it signed an international treaty called the Biological and Toxic Weapons Convention. Today, this treaty has been signed by over 170 other countries. The countries that have signed the treaty have agreed to destroy any biological weapons they have and not to build any more.

Current Issues

There is little chance today that biological weapons will be used between countries at war. However, there is a chance that terrorist groups may use biological weapons to kill some people and frighten others. Even a small group or a single person can cause widespread fear and tie up thousands of police, soldiers, and other workers with a small amount of a biological weapon such as anthrax. The U.S. government continues to study biological weapons in order to make vaccines that can protect people against them.

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[*See Also* **Vol. 1, Bioethics; Vol. 3, Security-Related Biotechnology.**]

Biomagnetism

Description

Biomagnetism is creation or use of magnetic fields by living things. Magnetic fields are created by magnets or in regions of electric current.

Whenever a muscle contracts or an impulse travels along a nerve, electric and magnetic fields are made. Observing how the fields made by the heart muscle or by the brain change over time can tell doctors how well those organs are working. An experienced heart doctor (cardiologist) can often tell exactly what is wrong with a patient's heart by looking at a record of its electric field as measured at the surface of the body, an electrocardiogram (ECG). A recording of the brain's electric fields is called an electroencephalogram (EEG). A recording of the heart's magnetic field is a magnetocardiogram (MCG), and a recording of the brain's magnetic field is a magnetoencephalogram (MEG).

Some living things not only produce magnetic fields, but detect them. The whole Earth is a magnet; everywhere on its surface there is a magnetic field that is more or less aligned from north to south. Many creatures, including some birds, fish, lobsters, turtles, bees, snails, bacteria, and mammals contain natural built-in compasses that sense the Earth's magnetic field. This extra sense, called magnetoreception, helps them to navigate.

Scientific Foundations

Some of the particles from which the world is made have electrical charges. Electrical charges are either positive or negative. The particles called electrons, for example, have negative electrical charge. Electricity, including lightning and sparks, consists of electrons in motion.

Woman undergoing electroencephalograph (EEG) testing, which measures electrical activity in the brain. *AJ Photo/Photo Researchers, Inc.*

Electricity and magnetism are like two different aspects of the phenomenon called electromagnetism, one of the fundamental forces of the universe. Every electrical charge causes an invisible electric field to exist around itself. An electric field pushes or pulls against other charges. Like charges repel each other; opposite charges attract. Electrical charges that are moving, or electric fields that change over time, also create (induce) magnetic fields. In turn, magnetic fields that change over time make electric fields. A ray of visible light or a radio wave (both electromagnetic waves) is really a pair of ever-changing electric and magnetic fields that bring each other into being as they move together through space. This self-creation and propulsion system is why light can travel across the vacuum of space and does not need a medium like a wave in ocean water.

Living things produce electric and magnetic fields. A nerve cell or muscle cell, for example, works to keep the concentration of certain kinds of charged particles inside itself different from the concentration outside itself. These different concentrations of charges cause an electric field to exist between the inside and outside of the cell. When a muscle cell contracts or a nerve cell

Transcranial Magnetic Stimulation

The human brain cannot, unlike the brains of many other creatures, sense the Earth's magnetic field. We have no built-in magnetic compass. However, the brain can be affected by magnetic fields. Rapidly changing magnetic fields, applied to the brain, can cause tiny currents to flow in its nerve cells. This method of affecting how the brain works is called transcranial magnetic stimulation or TMS. ''Transcranial'' means ''through the skull.'' TMS is transcranial because the device that applies the magnetic field is touched to the outside of the head. TMS has been found to be effective at treating depression, some hallucinations (hearing and seeing things that are not real), obsessive-compulsive disorder, and migraine headaches—often, more effective than any known drugs. As of 2006, researchers were still only beginning to understand all the ways TMS can be used to treat disorders of the brain.

sends a signal, the charged-particle concentrations inside the cell change briefly, so the electric field between the inside and outside of the cell changes too.

The electric field of a single muscle or nerve fiber is weak, but when the electric fields of thousands of muscle or nerve fibers change together, the combined field can be strong enough to be measured at the surface of the body. Since a changing electric field makes a magnetic field, the changing electric fields in muscles and nerves make magnetic fields. These can also be measured.

For magnetoreception, living things must have some way of detecting a magnetic field. One way is to use a particle of an iron compound that can act like a compass needle. Just like a compass needle, a particle of magnetic iron in a living cell tries to turn to line up with the Earth's magnetic field. Nerves can then sense the twisting of the particle.

Developlment

Experiments proving that some animals have the sense of magnetoreception were not done until the 1960s. It was also shown in the 1960s that some bacteria contain tiny particles of magnetite that they use as compasses. Today, many questions remain unanswered about how some animals sense the Earth's magnetic field. (Humans, as far as anyone knows, cannot.)

The magnetic field of the heart was first measured in 1967 by physicist David Cohen. In 1968, Cohen first measured the magnetic field of the brain (which is 500 times weaker than that of the

Words to Know

Electric field: A field created by electrically charged particles or a changing magnetic field. Electric fields created by nerve and muscle cells can be recorded and used to diagnose disease.

Electrocardiogram (ECG): A recording of the electric fields made by the heart, sensed as voltages on the skin of the chest and arms.

Electroencephalogram (EEG): A recording of the electric fields made by the brain, sensed as voltages on the scalp.

Magnetic field: A field created by moving electrical charges or by a changing electric field. Magnetic fields created by nerve and muscle cells can be recorded and used to diagnose disease.

Magnetocardiogram (MCG): A recording of the magnetic fields made by the heart.

Magnetoencephalogram MEG): A recording of the magnetic fields made by the brain.

Magnetoreception: The ability of some animals to sense the Earth's magnetic field.

Transcranial magnetic stimulation: The use of strong, rapidly-changing magnetic fields created by a device held by the head to induce electric currents in the brain. Used to study brain function and treat depression, hallucinations, migraines, and other disorders.

heart). He used bulky coils in his early experiments, but in 1969 he began using small devices capable of detecting very weak magnetic fields, SQUIDs (Superconducting QUantum Interference Devices). Today, SQUIDs are used in machines that help diagnose heart and brain problems by recording MCGs and MEGs. MEGs did not become practical until the late 1990s, and MCGs did not become practical until about 2003. MEG and MCG machines are still expensive and unusual compared to EEG and ECG machines.

Current Issues

Today, biomagnetism is a rich research field, both in medical imaging and in the study of how some animals use magnetoreception. The U.S. Department of Defense has launched a major research effort to apply magnetic fields to biological systems at very small size scales. One of its goals, for example, is to make magnetic tweezers that can handle individual molecules.

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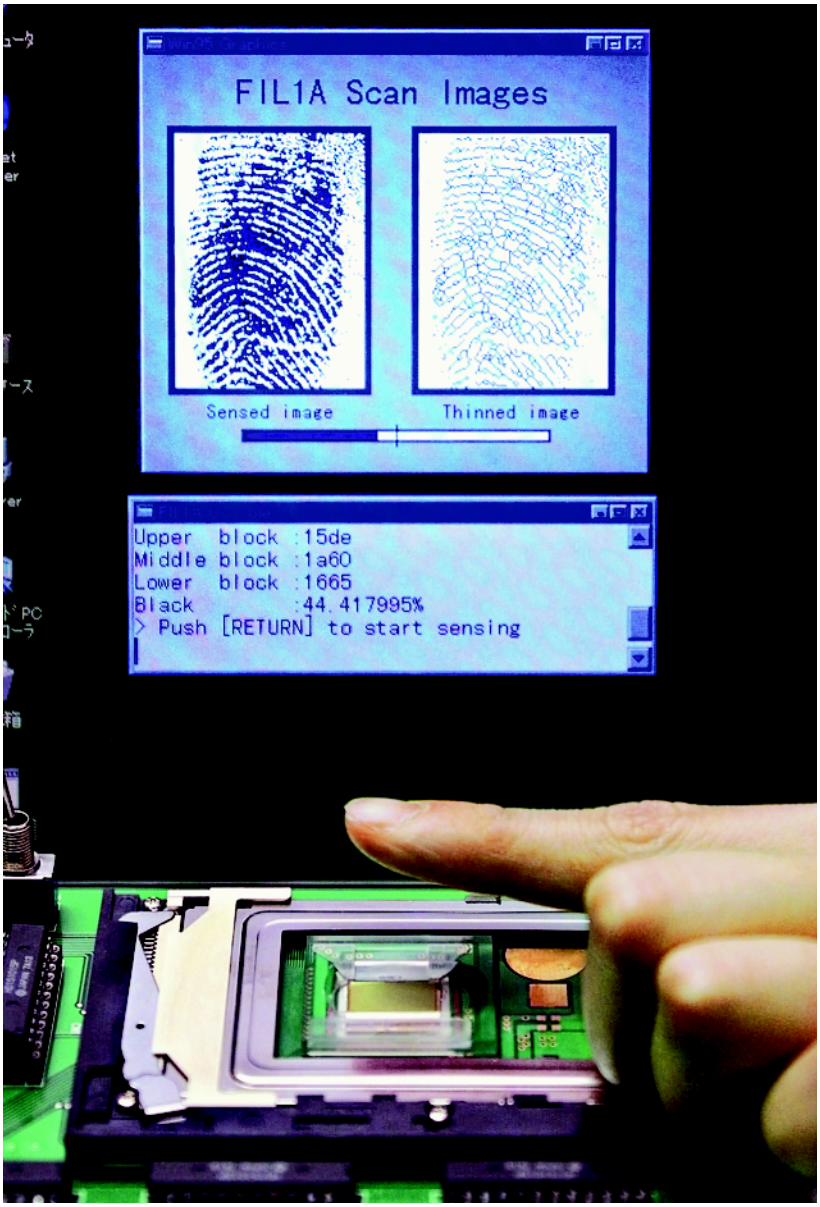
Biometrics

Description

Biometrics is the scientific study and technical application of various methods for verifying a person's identity. It identifies a person by using one or more biological (physical) characteristics or behavioral (social) traits. Biological characteristics include facial images, fingerprints, handprints and hand geometry, eye structure, retina (the innermost layer of the eye) scans, iris (the colored part of the eye) identification, and vascular (blood vessel) patterns. Behavioral traits include voice recognition, the way a person walks (gait), typing patterns, and signatures. All methods are considered reliable ways to distinguish between different individuals. These identification methods are currently in use in the United States and many countries of the world. They are considered much more reliable than using social security cards, photographs, secret passwords, or code numbers, which can be lost and copied. Biological and behavioral characteristics are unique to each individual and very difficult to alter or change.

A finger scanner is one example of a biometric device. A finger of the person to be identified is placed in the device (called a reader) and scanned. Then computer software converts the scanned information into digital form. The software is used to identify specific points of data as match points. The match points are processed within a database and changed into a numeric format. The database stores the data for later comparisons. When another finger is scanned by the reader, the database value is compared with the finger on the scanner. The computer will either indicate that the points match (real) or they do not match (phony).

Deoxyribonucleic acid (DNA) is also a way to identify individuals using biometrics. A sample of blood, hair, semen (liquid



```
Upper  block :15de
Middle block :1a60
Lower  block :1665
Black        :44.417995%
> Push [RETURN] to start sensing
```

Computerized fingerprint security system in Japan. Fingerprints are the most commonly used biometrics. *A/P Wide World.*

ejaculated from the penis), skin, or other body material is taken from a person and examined under a microscope. DNA identification is generally only used in criminal investigations.

Scientific Foundations

There are twelve major identification methods used in biometrics. Facial images analyze features of the face. Fingerprints look at

Fighting Terrorism and Buying Food with Biometrics

People in the United States and in many other countries around the world are concerned with terrorism. Consequently, biometric applications are becoming more popular and necessary. Government and private organizations are developing and promoting many biometric applications such as fingerprint scans, hand geometry, and retinal scans to defend against terrorism. For example, airport security in the near future will use face scanning and fingerprinting. Visitors crossing national borders may be tracked with biometric information on large databases. Transportation employees will have their biometric information readily available to authorities in case of trouble.

Along with national security, biometric devices can have applications in everyday life. Medicare patients will eventually scan their fingers to confirm their medical information. Livestock can be identified with retinal scanning tied to a global positioning system to allow their movements to be tracked when necessary. Grocery stores and other retail stores may use biometric devices to prevent the forgery of checks and the use of stolen credit cards.

the unique markings on the tips of each person's fingers. Handprints and hand geometry involves analysis of the shape and size of the hand and fingers. Eye structure analyzes the shape and features of the eyes. Retinal scans use the patterns of the blood vessels located at the back of the eyes. Iris identification scans the colored ring that surrounds the eye's pupil. Vascular patterns analyze the patterns of veins on the back of the hand and wrist.

Voice recognition uses the characteristics of a person's voice such as tempo, frequency, pitch, and tone. Gait analyzes the walking style of a person. Typing patterns measure the keystroke style of a person including the amount of time taken between typed words. Signatures are used because each person signs his/her name in a distinct way. DNA analyzes an individual's genetic makeup.

Development

Biometrics was first officially used in the 1880s when French police officer, anthropologist, and criminologist Alphonse Bertillon (1854–1914) developed a system of identification for convicted criminals. Bertillon based his system on physical characteristics such as eye color, scars, and deformities; body measurements such as body height standing and sitting, length from fingertip to fingertip, length and width of head and ears, and length of feet and fingers; and photographs. Within the Bertillon System of Anthropometric

Words to Know

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Encryption: The converting of text into difficult-to-understand code so that it is only readable by specific people.

Iris: Colored portion of the eye.

Retina: An extremely light-sensitive layer of cells at the back part of the eyeball. Images formed by the lens on the retina are carried to the brain by the optic nerve.

Identification (sometimes called Bertillonage), Bertillon recorded each measurement on cards for future reference. His system was used by law enforcement agencies throughout the world until it was learned that some people had the same body measurements and could not be easily identified.

Later, in the late nineteenth century, British scientist Sir Francis Galton (1822–1911) used fingerprints to identify people. His method replaced Bertillon's system because it was more reliable. The basis of today's classification of fingerprints to identify criminals, which originated with Galton's work, was developed by British police officer Sir Edward Richard Henry (1850–1931) in the 1890s. At the beginning of the twentieth century, biometrics used only fingerprints. Now, at the beginning of the twenty-first century, biometrics has expanded into at least twelve distinct methods.

Current Issues

Biometrics is considered a threat to privacy by some people and organizations. For example, biometrics may use a retinal pattern to identify a person, but the scan may also show that the person has a medical problem, such as high blood pressure. If personal information is misused, it could be, for instance, sold without the person's knowledge. On the other hand, the technical nature of biometrics makes it difficult for anyone to use personal information without permission. To prevent such problems, biometric data is encrypted (converted to code) when it is collected.

Many biometric methods are still expensive, such as DNA testing. However, some methods are being used more as costs come down. For example, voice patterns using microphones and computers and facial imaging using digital cameras and computers are already inexpensive to use. Fingerprinting is still the most often used and most reliable of the biometric methods. It is used frequently in legal and business areas. As biometric technology and its uses expand, laws and regulations are being made and standards developed. However, they continue to lag behind the technology, which is improving rapidly.

Although biometric devices are still in the early stages of development, many people feel that biometrics will become a very important technology in such fields as law enforcement, security, electronic commerce, and Internet communications.

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[*See Also* **Vol. 1, DNA Fingerprinting; Vol. 3, Fingerprint Technology; Vol. 3, Retina and Iris Scans; Vol. 3, Security-Related Biotechnology; Vol. 3, Smart Materials and Sensors.**]

Biomimetic Systems

Description

Biomimetics is the study of the structure, function, and formation of nature's living organisms, such as humans, other animals, and plants, especially for the purpose of imitating the characteristics of such natural organisms in the design of artificially made systems, mechanisms, and processes. In other words, biomimetics involves taking ideas from nature and applying them in technologies to benefit humankind. It is also known by such names as bionics, biomimicry, and bionical creativity engineering, among other terms.

Biomimetic systems are especially important in the development of electronic systems, such as computers. In its simplest application, people wear fins on their feet while swimming or diving in order to mimic the more-efficient swimming actions of frogs or fish. Applications that are more complex include the construction of airplanes and other flying craft after humans learned the principles of how birds fly. The Mercedes-Benz automobile company recently designed a bionic car that is built like the streamlined body of a fish.

Biomimetics has also been used to develop such products as audiovisual equipment based on the function of the human eye and ear; ships that mimic the physical structures of fish; artificial limbs that approximate the electrical activity in human muscles; and computer systems based on the nervous system of humans.

Specific examples of systems developed from natural organisms include sonar, radar, and ultrasound imaging scanners. These three systems were developed based partially on the study of how bats locate objects using echolocation. To locate objects, bats generate sounds that bounce off the object and then return to the bat. By studying this ability in bats, scientists were able to develop the

A two-year-old girl using her new bionic hand to pinch her mother's nose. © *Bob Collier/CORBIS SYGMA.*

electronic systems of sonar (the use of sound waves to locate objects underwater), radar (the use of reflected radio waves to find objects above water), and ultrasound imaging (the use of sound waves to see or treat structures inside the body).

Scientific Foundations

Biomimetic systems that humans create are based on biological systems that have evolved over thousands, even millions of years. Evolution is the process by which the characteristics of living organisms change over many generations as more favorable traits are passed down from one generation to the next. British naturalist Charles Darwin (1809–1882) suggested that all living organisms develop characteristics that make them stronger and more likely to survive and reproduce. Darwin described evolution as a living process of natural selection. Thus, when scientists develop artificial systems, they realize that the natural (biological) systems that they study are highly developed and efficient. As a result, they are confident that biological systems will provide very valuable insights into how to best design and build artificial systems.

Velcro® and George's Dog

In the 1940s, Swiss inventor and amateur naturalist George de Mestral walked his dog one day through a field of cockleburs, which produce small football-shaped burrs about one inch (2.5 centimeters) long. When he returned from the walk, George noticed that his dog was covered with burrs. Already an accomplished inventor, de Mestral placed one of the burrs under a microscope. He discovered that it had a stiff, hook-like shape, which is why it stayed attached to his dog's coat and his own pants. In nature, burrs carry seeds far distances by clinging to animals, such as dogs, as they brush past them. De Mestral's discovery of the way burrs cling onto things, led him to invent a hook and loop fastener where one side had stiff hooks like burrs and the other side had soft loops like the fabric of his pants. The two-sided fastener was named Velcro®, a combination of the French words *vel*our and *cro*chet. With his invention, de Mestral was able to improve on the zipper with the use of biomimetics.

Development

The concept of biomimetics is very old. Three thousand years ago, for example, the Chinese attempted to make artificial silk based on their observations of natural silk made by silkworms. In modern times, American biophysicist and inventor Otto Herbert Schmitt (1913–1998) helped to establish the field of biomimetics in the 1950s. He came up with the name biomimetics in 1969. The field was eventually nicknamed "the mimicry of nature" because Schmitt and other scientists saw many ways to imitate (or mimic) the living systems found in nature in machines and processes that could help humankind. In particular, Schmitt studied the nerves of squid, which helped him to invent the Schmitt Trigger, an improved electronic circuit device. He also developed medical electronic diagnostic methods and machines based on organisms found in nature.

In the last two decades, interest in biomimetics has grown rapidly because the techniques and technologies needed to study the natural world in detail are now available. In the 1990s, for example, cochlear implants—tiny electrodes placed in the cochlea to act like the ear's nerves—allowed deaf patients to hear almost normally. Cochlear implants are considered one of the most successful inventions based on biomimetic systems.

Biomimetics is still an emerging field. In 2004, English biomimetics professor Julian Vincent was developing smart clothing that changes its characteristics based on changes in temperature.

Words to Know

Cocklebur: A flowering plant whose seeds are produced in a spiny, double-chambered burr.

Evolution: In biology, inheritable changes occurring over a time span greater than one generation.

Radar: A method of detecting distant objects based on the reflection of radio waves from their surfaces.

Sonar: Sound Navigation and Ranging. A device utilizing sound waves to determine the range and direction to an underwater object.

Ultrasound imaging: Computer generated images of ultrasonic waves passed into the body.

He based smart clothing on his studies of pinecones and the way they change shape depending on moisture amounts. His smart fabrics open up when temperatures rise, but close with decreasing temperatures. Vincent and other scientists recognize that many opportunities exist for scientists to make discoveries and inventors to design and build products based on biomimetic systems. Other inventions that are in development include airplane wings that change their shape according to the speed and length of a flight. The wings were developed by looking at the shapes and structures of wings of many different types of birds and comparing wing shape to the bird's typical flight speed. Different sections of these new airplane wings also move depending on conditions of the flight. Their movement was inspired by the moveable scales of fish.

Current Issues

Living organisms do not necessarily provide all of the solutions for artificially made systems. Sometimes organisms do not exhibit better performance than engineered systems. However, for the most part, many superior features of organisms can be studied and used for the improvement of human technology.

Not everyone, not even all scientists, believes that the theory of evolution explains how the many animals and plants in the world today, as well as those that existed in the past, came to be. Regardless, many living organisms are far superior in design and function to what humans have developed so far. The study and application of the characteristics of these natural organisms to the development of artificial systems and devices offer enormous potential for future technologies and improvement of current technologies.

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[*See Also* **Vol. 3, Biodetectors; Vol. 1, Bioethics; Vol. 3, Biorobotics; Vol. 3, DNA Computing; Vol. 3, Nanotechnology, Molecular; Vol. 3, Smart Materials and Sensors; Vol. 1, Synthetic Biology.**]

Bioplastics

Description

Many of the products people use every day are made from plastic. From milk containers to the bags used to carry groceries, plastics have become part of human life. Plastics are made up of polymers—chemical compounds made up of long chains of smaller molecules. Although plastics are useful, to manufacture them requires petroleum, a type of fossil fuel (a carbon-based fuel source, such as oil and gas, which is made from fossilized plant and animal remains). There is concern that these types of fuels are harmful to the environment. Also, plastic is not biodegradable. This means that it cannot be broken down by living things, such as bacteria, which would normally degrade natural materials. When things made of plastic are thrown out, they build up in trash piles.

An alternative to petroleum-based plastic is bioplastic. This plastic-like material is made from biopolymers—long-chain molecules that are made in living organisms. The raw materials for bioplastics are starchy crops such as soybeans, corn, beets, and potatoes. Bioplastic can be used to make many of the same products as can regular plastic, such as shopping bags and plastic wrap, but it is biodegradable.

Scientific Foundations

There are two main methods for making bioplastics: fermentation using bacteria and genetic engineering. Fermentation is a process in which bacteria break down sugar in the absence of oxygen. The bacteria use the sugar as energy, and produce various substances (such as alcohol or lactic acid) as byproducts.

Genetic engineering is the process by which scientists transfer a desired trait from one organism to another. For example, they

BD·CUP
BIODEGRADABLE CUP
BD·CUP
BIODEGRADABLE CUP

Biodegradable plastic cups created from materials made by genetically modified bacteria. © *Roger Ressmeyer/CORBIS.*

might genetically engineer a goat with human proteins so that the goat produces the proteins in its milk. Genetic engineering involves finding and transferring the segment of DNA that codes for a particular trait from one organism into the DNA of another organism. DNA is the double-stranded chain of genetic information that is held in the nucleus of nearly every cell.

Development

The first human-made plastic was invented by a British chemist named Alexander Parkes (1813–1890). He displayed it in 1862 at the Great International Exhibition in London. People called his plastic Parkesine.

Cellophane was the first biodegradable plastic. Jacques E. Brandenberger (1872–1954), a Swiss inventor, produced it from a carbohydrate in plant cell walls called cellulose. Cellulose is a type of biopolymer. In the 1970s, scientists began looking at another biopolymer—starch. They mixed it with regular plastics to try to make plastics more degradable. In the 1980s, researchers learned how to combine synthetic (made in a laboratory) polymers with biopolymers to make a

Bioplastics Make Cars More Green

Bioplastics have many uses, from bags to storage containers. But another major use for them is in a product usually made from metal and wood: the car. As far back as the early 1900s, American auto maker Henry Ford (1863–1947) developed a method for making car parts out of soybeans. Today, several big car manufacturers have replaced many of the oil-based and wooden car parts with bioplastics. The Japanese company, Toyota, has its own biotechnology division in which it manufactures bioplastics.

product that had the best features of each. Then in the 1990s, they learned that bacteria called *Lactobacilli* can produce lactic acid from corn sugar. Lactic acid could then be converted into a biopolymer.

Today, bioplastics are made by fermentation and by genetic engineering. There are two types of fermentation that can be used to produce plastics. The first is lactic acid fermentation. Crops such as corn and beets naturally contain a lot of sugar. Bacteria contain enzymes (proteins that are involved in chemical reactions) that break down those sugars in the absence of oxygen. The bacteria use the sugars for energy and produce lactic acid as a byproduct. People can then convert the lactic acid into a bioplastic by a process that links the molecules together into long chains that form a polymer. This process is called polymerizing.

In another form of fermentation, certain types of bacteria use the sugar of corn and other plants for energy. Just as humans and animals store energy in the form of fat, the bacteria store energy as a polymer. The polymer can be taken out of the bacterial cells and used to make bioplastics.

Bacteria contain certain genes (segments of DNA that code for a certain protein) that enable them to manufacture and store the plastic polymer. Because bacteria do not produce this polymer efficiently, scientists have genetically engineered plants with genes from bacteria. Scientists isolate and remove the genes from the bacteria and insert them into a plant's DNA. This causes the plant to be able to produce polymers. Plants can produce polymers more efficiently than bacteria.

Current Issues

Bioplastics are biodegradable, and they are not toxic (poisonous) to humans or animals. One of the main reasons for developing bioplastics is to reduce the amount of fossil fuel used, although some of these fuels are still required to produce bioplastics.

Words to Know

Biodegradable: Able to be broken down by natural processes.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Enzyme: A protein that helps control the rate or speed of chemical reactions in the cell.

Fermentation: The process of breaking down sugar without oxygen into simpler substances, commonly alcohol and carbon dioxide.

Fossil fuel: A fuel that is derived from the decay of plant or animal life; coal, oil, and natural gas are the fossil fuels.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Genetic engineering: The manipulation of genetic material to produce specific results in an organism.

Lactic acid: A carboxylic acid formed during the metabolism of sugar in muscle cells. A buildup of lactic acid leads to a feeling of fatigue.

Polymer: A chemical compound formed by the combination of many smaller units.

Polymerizing: The process by which smaller chemical units are linked into a chain to form a polymer.

Toxic: Something that is poisonous and that can cause illness or death.

Researchers are trying to find other ways to manufacture bioplastics to avoid the need for nonrenewable fuels. One big downside to producing bioplastics is that the process is not yet efficient. Because bioplastics require more effort to produce, they cost a lot more than petroleum-based plastics.

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[*See Also* **Vol. 3, Biodegradable Packaging and Products; Vol. 3, Biorubber; Vol. 2, Corn, Genetically Engineered; Vol. 3, Fermentation, Industrial; Vol. 2, Transgenic Plants.**]

Bioreactor

Description

A bioreactor is a system or device that allows a controlled environment for organisms like bacteria (one-celled germs) or yeast (a one-celled type of fungus) to grow. A typical bioreactor is a tube-like container that is constructed of stainless steel; the device ranges in size from foot-long versions that can sit on a desk to some that are ten feet (three meters) or more in length and have a capacity of hundreds to thousands of gallons. The largest ones are dedicated units that are anchored to the floor and often housed in their own rooms. Another bioreactor design that incorporates a surface in the reactor allows cells or tissues (collects of similar cells) to grow.

The biological reactions that occur inside of a bioreactor can be aerobic (oxygen-requiring) or anaerobic (requiring the absence of oxygen).

Bioreactors are important in the manufacture of compounds in the biotechnology and pharmaceutical (medical drug-making) industries, and in the treatment of water and wastewater.

Scientific Foundations

Bioreactors are vessels that allow biological reactions to proceed in a well-controlled way. Bioreactors contain a culture, the term used to describe the mixture of microorganims and growth medium (usually a specially formulated nutrient liquid). (Microorganisms are tiny living things, like bacteria and yeast, that can only be seen with a microscope.) For this to occur, most bioreactors are designed with a number of ports that allow for the culture to be monitored for aspects including pH (a chemical measure of acidity that influences how bacteria and yeast grow); presence and

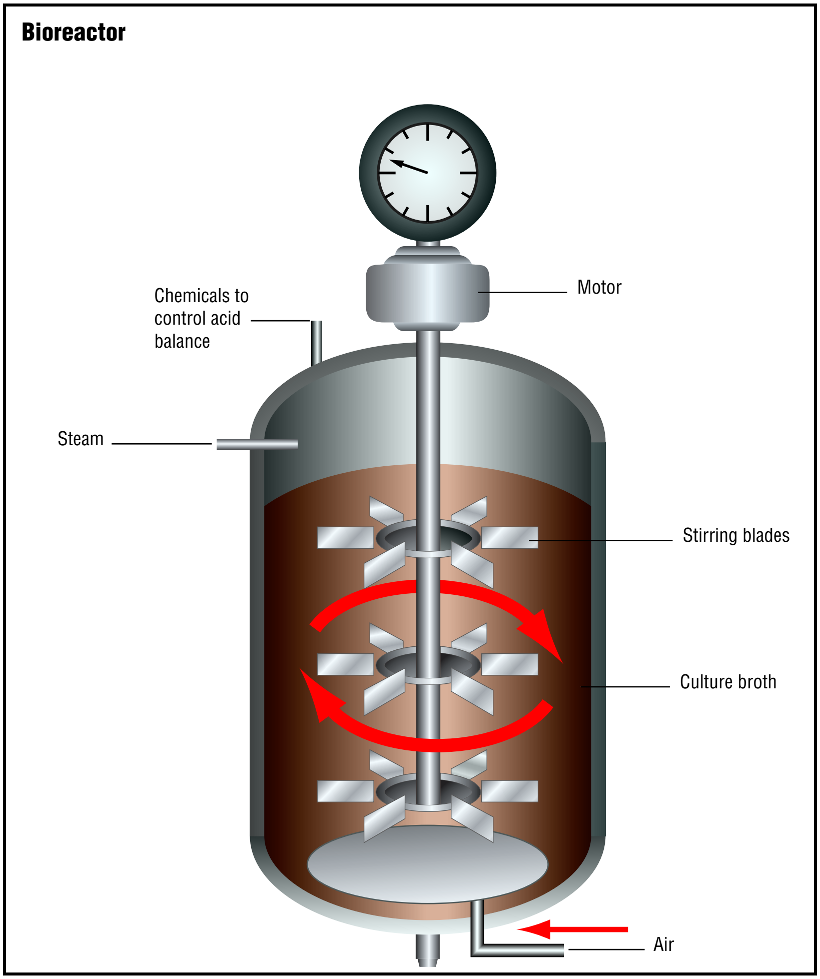

Diagram of a bioreactor. A culture broth contains microorganisms in a nutrient liquid. Clean air is allowed in, steam escapes, and chemicals can be added to keep the environment stable. *Illustration by GGS Inc.*

amount of gases such as oxygen, nitrogen, and carbon dioxide; and temperature. These parameters can be maintained at the desired levels by the addition of the appropriate agents. For example, the bioreactor can be heated or cooled, chemicals that influence pH level can be added, and gases can be added or allowed to escape. In addition, a bioreactor is usually equipped with a stirring device to keep the microorganisms evenly suspended. Some experimental bioreactors, however, deliberately allow the microorganisms to settle in one area by introducing an interior surface that can be colonized.

Bioreactors typically operate in one of three modes. The first is referred to as a batch mode. In this mode, the growth medium and microorganisms are added to the vessel, which is then sealed. Growth and the related biological reactions occur in a closed system, although

Bioreactors and Reduced Gravity

A special type of bioreactor has been used to generate cells and tissues under conditions of lower gravity. The bioreactor is positioned horizontally, instead of vertically as is usually the case. In addition, the chamber in which growth takes place can rotate. These two conditions cause the developing cells to experience reduced gravity while their growth occurs in three dimensions. The three-dimensional growth allows cells to develop as they would naturally, compared to the two-dimensional conditions of conventional growth in the lab, which is less successful. Using a bioreactor in which a chamber rotates horizontally, scientists have generated heart tissue that is so true to natural heart tissue that it may provide material for transplantation.

monitoring of the reactions is possible. The reactions are ended when the vessel is opened and the culture collected.

In the fed batch mode of operation, the bioreactor is equipped with an inlet and an outlet. This permits fresh growth medium to be added and culture withdrawn. Addition and withdrawal are manual operations and do not have to occur at the same time.

Finally, in a continuous flow bioreactor the addition and removal processes do occur at the same time and at the same rate. This is useful when a nutrient is absolutely required by the growing microorganism and when the nutrient content of the growth medium is controlled. Using this so-called defined medium, the rate at which the microorganisms grow can be linked to the rate of addition of the required nutrient. Withdrawing culture at the same rate keeps the culture volume constant. This type of bioreactor can be useful in researching the biochemical properties of a microorganism, which can vary with the rate of growth.

Bioreactors allow environmental conditions to be precisely controlled. This can be important, because some microorganisms may produce a compound in one environmental circumstance but not in another. Also, the huge volumes of industrial-scale bioreactors allow a lot of compound to be produced and harvested. For example, bioreactors are used to grow *Escherichia coli* that are genetically engineered to produce human insulin, enabling there to be enough quantities of the life-saving compound to be manufactured for sale.

Bioreactors used in the treatment of water and wastewater include a membrane. Microorganisms collect and grow on the membrane, and can then use incoming water for their growth, which helps degrade unwanted compounds.

Words to Know

Aerobic reactions: Reaction that require oxygen or that take place in the presence of oxygen.

Anaerobic reactions: Reactions that take place in the absence of oxygen.

Bioreactor: A container used for bioprocessing.

Development

Membrane bioreactor technology has advanced with the development of membranes that have exceedingly small pore sizes. These ultrafiltration membranes enable particles as small as viruses (very small microorganisms that often cause disease) to be trapped and removed from filtered water.

Bioreactors have been developed to the scale of a landfill (garbage dump covered with layers of dirt). By the addition of liquid and air to the buried waste, the decomposition of the buried material can occur more quickly than occurs in a conventional landfill. As of 2006, the United States Environmental Protection Agency is assessing the merits of the bioreactor landfill and is in the process of formulating operating guidelines for their construction and use.

Current Issues

Research continues to better understand the reaction dynamics of large-scale bioreactors. Reaction conditions such as the movement of fluid can differ in a large reactor, as compared to a small, bench-scale reactor. The different conditions will affect the performance of the microorganisms and the compounds they produce. Bioreactor research usually begins with a small reactor and progresses to larger reactors.

Bioreactor landfills represents the extreme in bioreactor operation scale. Such landfills need to be carefully designed and maintained, so that the surrounding environment is not affected.

The behavior of genetically modified organisms that are grown in bioreactors continues to be studied, to detect and correct unforeseen problems, and to improve the process so that the production of the desired compound is the best possible and can be predicted over time.

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[*See Also* **Vol. 3, Enzymes, Industrial; Vol. 3, Fermentation, Industrial; Vol. 1, Insulin, Recombinant Human; Vol. 1, Tissue Engineering.**]

Bioremediation

Description

Bioremediation involves various environmental techniques that use microorganisms (microscopic organisms) to remove pollutants from soils, liquids, and gases. One of the most commonly used microorganisms is bacteria (one-celled germs). In the first half of the 2000s, the process of bioremediation was used in about five to ten percent of all pollution treatment procedures.

The microorganisms in bioremediation use biological chemicals called enzymes to break down or biodegrade pollutants. This natural process is often used by humans for the treatment of agricultural, industrial, and municipal wastes. Bioremediation usually takes place in several stages. A different microorganism is often used in each step to metabolize (chemically break down) a specific toxic (poisonous) substance into a nontoxic substance.

Bioremediation is done in one of two ways—either *in situ* or *ex situ*. *In situ* bioremediation treats contaminated material at the contaminated location, while *ex situ* bioremediation moves the contaminated material to another location for treatment. A variety of specific techniques and technologies are used in bioremediation including:

- Bioaugmentation: introducing microorganisms to treat human and industrial wastes
- Bioreactor: a large chamber for growing microorganisms to use in bioremediation
- Biostimulation: using nutrients for decontamination
- Bioventing: supplying oxygen to soil microorganisms to increase their activity

These genetically engineered cottonwood trees in Connecticut are used to decontaminate soil polluted with mercury. *AP Images.*

- Composting: manipulating plant and animal materials so that they are gradually broken down by soil bacteria and other organisms
- Landfarming: mixing contaminated material into soil and turning it periodically to introduce air and speed decomposition
- Rhizofiltration: using plant roots to remove contaminants from groundwater.

Several environmental techniques are used in bioremediation. Each technique depends on the specific microorganism used and the particular pollutant treated. Most techniques involve the removal of one or more pollutants—in many cases gasoline or oil. For example, bioremediation has been used frequently to clean underground storage tanks that leak gasoline. In this case, the leaking tank is dug out and removed. Then, nutrients, such as fertilizers containing nitrogen and phosphorus, are added to the soil that was under the leaking tank. The soil is then broken up to add oxygen, which speeds the biodegradation process.

Bioremediation Used for the Exxon *Valdez* Spill

In 1989, the oil tanker Exxon *Valdez* spilled its cargo of oil onto the beaches at Prince William Sound in Alaska. Bioremediation was used to clean some of the pollutants contaminating the shoreline. Exxon, the company that owned the ship, agreed to use bioremediation after the U.S. Environmental Protection Agency (EPA) performed a test of bioremediation. EPA scientists used fertilizers to rapidly grow microorganisms that were already present in the sand and rocks where the spilled oil occurred. One section of beach was treated with fertilizers, while another part of the beach was left alone. The bacteria grew faster because the fertilizer provided them with more nitrogen and phosphorus than was present naturally. The bacteria used these elements as food. Based on the test, the EPA recommended the use of bioremediation for the clean-up.

Scientific Foundations

Pollution refers to the presence of any material that hurts the Earth's environment by harming its natural ecosystems (which include plants, animals, and their surroundings) or by causing human health problems, such as cancer. Most pollution is caused by people, but some pollution is produced naturally, such as animal wastes, smoke from forest fires, and gas and ash from volcanoes eruptions.

Degradation is the process by which a substance breaks down quickly and safely into its components. Biodegradable substances can be broken down by the action of living things, usually microorganisms. For example, crude oil breaks down to produce carbon dioxide, water, and some biologically inactive byproducts. However, after crude oil is made into plastic, for example, microorganisms may not be able to break it down. When this happens, the plastic remains in that form for a long time. Scientists consider it non-biodegradable, or, unable to be broken down.

Development

Bioremediation techniques in various simple forms have been used for several centuries. For example, farmers have used plants to remove salts (which harm their crops) from their fields. During the 1960s, American petroleum engineer George M. Robinson performed experiments with microorganisms and abandoned oil pumps in California. In 1969, Robinson completed what is now considered the first large-scale commercial clean-up of an oil spill with microorganisms. He treated a spill in Santa Barbara County with bacteria he created in his home laboratory.

Words to Know

Ecosystem: A group of organisms and the environment they inhabit.

***Ex situ*:** A Latin term meaning ''from the place'' or removed from its original place.

Fertilizer: An agricultural product that is added to soil to provide nutrients and increase crop productivity.

***In situ*:** A Latin term meaning ''in place'' or in the body or natural system.

Metabolize: Any cellular activity that converts nutrients to energy.

Microorganism: An organism too small to be seen without a microscope, such as a virus or bacterium.

Polychlorinated biphenyls (PCBs): A compound of biphenyl and chlorine that is considered a hazardous pollutant.

Robinson cleaned pollutants from tanks on the *RMS Queen Mary* and other ships, waste runoff in zoos, sewage from treatment plants in cities, and grease build-up in restaurants. By 1972, over 4,500 oil spills had been cleaned up in California based on Robinson's pioneering work. Robinson is now considered the have developed the general process of bioremediation.

Robinson's daughter, Mery Robinson, later founded U.S. Microbics, which is headquartered in Carlsbad, California. U.S. Microbics is the first corporation in the United States to develop, manufacture, and sell products based on the work of microorganisms.

Current Issues

Bioremediation is one of the least expensive ways to clean up pollution. It also causes only minor problems to the surrounding area when compared to other pollution clean-up methods. However, bioremediation is still one of the least successful clean-up methods. Some compounds do not biograde very easily using current bioremediation technologies. For instance, polychlorinated biphenyls (PCBs, industrial chemicals no longer in use) are very hard to remove from soil using bioremediation.

Bioremediation is still an emerging technology for cleaning soil, water, and many other environments. With more research and development, it has great potential for creating new and better organisms designed to remove contaminants from damaged environments. Officials with the U.S. Environmental Protection Agency (EPA) have stated that by learning more about the basic science behind bioremediation, waste treatment companies will better be able to treat contaminated materials, save money in clean-up costs, and operate safely within the natural environment.

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[*See Also* **Vol. 2, Compost/Organic Fertilizers; Vol. 3, Enzymes, Industrial; Vol. 2, Soil-Modifying Bacteria; Vol. 3, Wastewater Treatment.**]

Biorobotics

Description

Technology is constantly improving, and machines can now accomplish tasks that were not imaginable fifty years ago. But, although machines can do many things, they still cannot adapt to the world around them. That is something that only living organisms, such as animals and insects, are able to do.

Scientists are starting to learn how to combine the adaptive abilities found in nature with the power and durability of machines. The term for this is biorobotics, and it combines two fields: biology and robotic engineering. Scientists are starting to build robots that can perform actions normally accomplished only by humans, animals, and other living organisms.

Biorobotics has many potential uses. It can be used to make artificial (human-made) limbs that help people with disabilities get around and take care of themselves. It can be used to create special machines that can go places too dangerous for humans to travel, and perform tasks that would be too difficult for people to accomplish. Biorobotics also can help biologists better understand how animals move and respond to their environments.

Scientific Foundations

Biorobotics combines the fields of biology and robotic engineering. Biologists study how animals interact with and respond to their environment. They watch very closely to see how the animals move, how they see, and how they navigate. Then engineers use that information to design and build robots—machines that can perform similar tasks.

A robotic toy dog called ''AIBO.'' AIBO is able understand voice commands and learns through experience. © *Haruyoshi Yamaguchi/CORBIA SYGMA.*

Development

The roots of biorobotics go back many years. Scientists have long borrowed from nature to develop new inventions. In the early 1940s, a Swiss inventor named George de Mestral returned home from a walk with his dog, when he noticed that his dog had burrs stuck to its fur. Careful inspection of the hook-like burrs led to Mestral's invention of the Velcro fastener.

The word robot comes from a 1921 play named *R.U.R.* by the Czech writer Karel Capek (1890–1938). Science fiction author Isaac Asimov (1920–1992) was the first to use the word robotics in a story he published in 1942. The first industrial robot, called

Biorobots in the Military

Bats are well known for their ability to navigate in the dark using echolocation. After emitting a sound, these bats can tell the distance, direction, size, surface texture, and material of an object from information in the returning sound wave or echo. Scientists at the U.S. Office of Naval Research are trying to use what they have learned about bat echolocation to improve their own radar systems. Their research has also extended to other types of animals. Lobsters, for example, have a keen sense of smell underwater and can move easily in shallow water. Scientists have created a robotic lobster, called RoboLobster, which might one day be used to find and destroy mines (explosive devices used in warfare) in shallow water.

Unimate, worked at a General Motors car plant in the early 1960s. Then, in 1966, researchers at Stanford University in California built Shakey, the first mobile robot created with artificial intelligence (a computer brain that can use reason and learn).

In biorobotics, biologists carefully study animal and insect behavior. Engineers then use what the biologists have learned to build more useful machines that can respond to different environments. For example, when an animal walks, it can alter its movements to climb hills or avoid holes. This ability enables cockroaches, which are very small, to run very long distances over very rough terrain. Researchers have used what they have learned about cockroaches to design six-legged robots that can travel easily over very rough ground. These multi-legged robots may one day be used to explore Mars.

Scientists also have examined the way animals navigate. They have studied the way wasps and bees look back at their nest from different angles as they leave it, in order to find their way back. Researchers in Australia have modeled a camera after that ability. The camera records images of an area and its landmarks as it leaves the area. The images are then used to create a map in a robot's brain that helps it navigate.

Scientists also have designed robots with insect-like antennae (flexible sensory appendages on an insect's head that help it find its way around), so they can follow a scent. These bug-like robots could be used to find people who are lost or to track down dangerous substances, such as explosives or leaking gas. Tiny robots also could be made to act like scouts, traveling into areas that would be too remote, too small, or too dangerous for humans to go into.

Words to Know

Antennae: Small sensory projections on the front section of the head.

Artificial intelligence: Devices that attempt to reproduce or exhibit human-like intelligence and behavior.

Biologist: A scientist who studies biology (the science of living things).

Biorobotics: The use of living organisms to create or modify robots or robotic devices.

Such robots could be used in the military to protect troops from attack or to patrol borders. Flying robots might one day have the same abilities—and be about the same size—as a housefly.

Current Issues

Scientists are making great strides in biorobotics, but they are still many years away from creating a robot that can move as well as an animal or react to its environment as effectively. Researchers are still trying to understand exactly how movement and other natural functions are controlled in living organisms. Future experiments and studies on animal and insect models will help them gain a better understanding of how these functions work. What they learn from these studies will help scientists build more life-like robots in the future.

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[*See Also* **Vol. 1, Biochip; Vol. 3, Biomimetic Systems; Vol. 3, Nanotechnology, Molecular; Vol. 3, Smart Materials and Sensors; Vol. 1, Synthetic Biology.**]

Biorubber

Description

Biorubber is a new type of material created in the laboratory for medical use. It is a stretchy kind of polymer, a name for a group of materials made of many smaller molecular pieces. Biorubber is also biodegradable (degrades quickly and safely through the action of living organisms) and biocompatible (safe for use inside the human body). Its two main ingredients are glycerol, a syrupy liquid found in fats and oils; and sebacic acid, a white sparkling acid. (Acids are very strong liquids that have a sour taste, like citric acid in oranges.) The property that makes biorubber different from other polymers is its ability to return to its original shape after stretching. In fact, it is so stretchy that it is compared to rubber bands.

Most biological materials used before biorubber were hard and brittle. These characteristics made them difficult to use in medicine because most tissues and organs are flexible. For example, the air sacs in the lungs stretch to many times their normal size when a breath is taken. Therefore, researchers wanted to invent a material that could act like natural tissues and organs. Biorubber meets those requirements, especially for use in drug delivery, medical devices, and tissue engineering. Some of the many uses for biorubber include the making of bioengineered blood vessels, bones, cartilage (the hard but flexible material in the nose and ears), heart tissue, heart valves, and various other tissues. Eventually, complete organs needed for transplantation, like hearts and lungs, could be made with biorubber.

Scientific Foundations

Polymers are natural or synthetic compounds that include large molecules made of many smaller identical molecules (or units)

Biorubber and Chewing Gum

Its inventors describe biobubber as a piece of rubber that is biodegradable and biocompatible. While the medical community is very interested in biorubber as an improved way to make artificial organs and tissues, the chewing gum industry is also interested in it. Two leading chewing gum manufacturers have shown strong interest in biorubber as a substitute for today's gums that are non-biodegradable and indigestible. One of the inventors of biorubber says that if a person were to spit already chewed biorubber onto a sidewalk, the material would disintegrate within a few months. Gum made today does not decompose and is not digested when swallowed. If biorubber is eventually is used in chewing gum, then the days of finding old chewing gum under desktops and movie seats would be over

that repeat themselves. These repeating molecules are called monomers. Materials with many repeating units are called high polymers, and polymers with only one type of repeating unit are called homopolymers. Copolymers are polymers made from many different repeating units. Most natural substances such as rubber, protein, and wood are polymers. Synthetic (artificially made) materials, such as nylon, plastics, and glass, are composed mostly of polymer-like substances.

Biorubber can act as a biological scaffolding for the engineering of tissues. A biological scaffold is a structure used to support growing cells. After cells have grown into new tissues and they are able to function on their own, biorubber is absorbed into the body. That is, biorubber imitates the stretchiness of natural tissue until the body is finished with it. Then, it is removed by the body.

Development

In the mid-1990s, American engineer Robert Langer, a professor of chemical and biomedical engineering at Massachusetts Institute of Technology; along with Yadong Wang, a research associate in chemical engineering; Guillermo A. Ameer, a chemical engineering postdoctoral associate; and Barbara J. Sheppard, a comparative pathologist, invented biorubber. The National Heart, Lung and Blood Institute, a part of the National Institutes of Health, sponsored their work. Their research results appeared in the June 2002 issue of the journal *Nature Biotechnology*.

Due to the many possible uses of biorubber, it is already being tested in such countries as the United States, England, Japan, New

Words to Know

Biocompatible: Able to live or exit together. Not harmful or mutually beneficial.

Biodegradable: Able to be broken down by natural processes.

Elastomer: An organic polymer that has rubber-like, elastic qualities.

Monomer: A substance composed of molecules that are capable of joining together to form a polymer.

Polymer: A chemical compound formed by the combination of many smaller units.

Synthetic: Referring to a substance that either reproduces a natural product or that is a unique material not found in nature, and which is produced by means of chemical reactions.

Tissue: Groups of cells with a similar function.

Tissue engineering: Artificial products that are made from natural biological materials.

Toxic: Something that is poisonous and that can cause illness or death.

Transplantation: Moving cells or tissues from their point of origin in one organism to a secondary site in the same or a different organism.

Zealand, and Singapore. These preliminary studies have already shown that biorubber is a stable material at body temperature, keeps its original characteristics when placed in water, and has the ability to stretch many times and return to its original shape. Scientists have found that when it is made in a pure form, it looks like the human body's ligaments (tissues that connect bones together) and veins.

Current Issues

Some advantages of biorubber are its strength, biocompatibility, biodegradability, and inexpensive price. It does not cost much when compared to similar materials because researchers have been able to make large amounts of biorubber. Its characteristics are also easily altered by changing the ratio of glycerol and sebacic acid. A certain amount of each ingredient is used, for example, to produce biorubber that degrades slowly in the body.

Biorubber has not been approved for human use by the U.S. Food and Drug Administration (FDA). It must first go through a strict approval process. However, the FDA has already approved sebacic acid and glycerol is a common ingredient that is already considered safe. Both ingredients are nontoxic. Biorubber has shown promising results in animal testing.

Millions of people in the United States suffer organ failure and tissue loss each year. Only about one in ten of these people receives organ or tissue transplants; most die while waiting. Tissue engineering is an emerging scientific field that involves growing living cells that organize themselves into replacement body parts. These artificially made tissues are then able to perform normal biological functions in the human body. Upon approval by the FDA, the ability to use biorubber to make organs and tissue has the potential to save millions of lives each year around the world.

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[*See Also* **Vol. 3, Biodegradable Packaging and Products; Vol. 1, Organ Transplants; Vol. 1, Synthetic Biology; Vol. 1, Tissue Engineering.**]

Biosafety Level Laboratories

Description

Biosafety levels are safety standards for laboratories that handle dangerous bacteria and viruses. There are four biosafety levels. The least safe or secure level is Biosafety Level 1, and the most secure is Biosafety Level 4. The purpose of biosafety levels is to keep dangerous bacteria and viruses from escaping. The more dangerous the germs in a laboratory are, the higher its biosafety level should be.

The four biosafety levels are:

- *Biosafety Level 1.* This level is for laboratories handling bacteria and viruses that are not known to make healthy people sick. A Biosafety Level 1 lab has simple safety features: a door to keep visitors out while work is being done, a sink for handwashing, acid-proof tables and benches, warning signs to post on the door when radioactive or poisonous chemicals substances are being used, goggles to protect workers' eyes, and so on. A teaching laboratory at a college is a Biosafety Level 1 laboratory.
- *Biosafety Level 2.* This level is for laboratories handling bacteria and viruses that are fairly risky, but not deadly. These include germs that people are commonly exposed to, such as cold viruses or the bacteria that cause strep throat. The workers in such a laboratory are usually immune to these agents because they have been exposed to them before, often as children. All the safety precautions from Biosafety Level 1 are also taken in a Biosafety Level 2 laboratory, plus others. Fewer visitors are allowed; no animals are allowed to visit; all spills and accidents have to be noted in writing; bacteria or viruses must be moved in leak-proof boxes; and any work that

A scientist working in a Biosafety Level 4 laboratory at the U.S. Centers for Disease Control in Atlanta. Level 4 is the highest level of safety for working with dangerous viruses. © *CDC/PHIL/Corbis.*

might cause dangerous agents to spray or splatter has to be done using special gear that keeps the droplets from escaping.

- *Biosafety Level 3.* This level is for laboratories handling bacteria and viruses that can cause deadly disease if breathed in. Fans move the air through the building so that it always flows from safer areas to more dangerous ones, such as from the hallway into the laboratory. Before leaving the building, the air is filtered to catch any germs. People working in the laboratory must wear special filter masks. The bacteria that cause tuberculosis and the viruses that cause encephalitis are handled in Biosafety Level 3 laboratories.
- *Biosafety Level 4.* This is the level of biosafety needed for the most dangerous viruses. No bacteria, fungi, or parasites are known to be dangerous enough to need Biosafety Level 4. All work must be done using Class III biological safety cabinets,

Accidents Do Happen

So far, germs have never escaped from a Biosafety Level 3 or 4 laboratory and made people sick in the outside world. However, there have been a few close calls. One day in December 2002, electrical power failed for three hours at the Plum Island Animal Disease Center near Long Island, New York. The lab had three backup generators to make electricity, but all three failed. Without any power, the air in the laboratory started to lose pressure after fifteen minutes. Lab workers used duct tape to seal the doors. Nobody was hurt, but the accident showed that even high levels of biosafety are not always perfect.

which are air-tight boxes with attached rubber gloves. A worker can handle objects inside a Class III cabinet without ever touching the objects or the air around them. A Biosafety Level 4 laboratory can cost over $160 million to build. There are only four Biosafety Level 4 laboratories in the United States, one in Canada, and a few others around the world.

Scientific Foundations

Biosafety levels are needed because some bacteria and viruses are more infectious and deadly than others. Common colds are infectious—that is, the viruses that cause them are easy to get—but they are not deadly to most people. Ebola virus, however, is not only infectious but deadly. It and other deadly viruses must be studied in Biosafety Level 4 labs. Less dangerous diseases could also be studied in Biosafety Level 4 labs, but it would cost too much. Biosafety levels are meant to make it less likely that a dangerous agent will infect a person working in the lab or escape to the outside world.

Development

Starting in the 1940s, studies found that people working with germs in laboratories often got sick. They would breathe in or swallow the germs without knowing it. There were no standards or guidelines saying exactly how to handle dangerous bacteria and viruses in the laboratory.

In 1974, the Centers for Disease Control—an agency of the U.S. government—issued a booklet called *Classification of Etiologic Agents on the Basis of Hazard*. The booklet defined four levels of danger when working with bacteria and viruses.

Words to Know

Biosafety: The safe handling of bacteria and viruses. Four levels of biosafety are officially defined for laboratories that handle bacteria and viruses.

Biosafety cabinet: A box in which biological laboratory work may be done safely. It either sucks air in to keep germs from escaping, or is completely sealed against the outside air.

Bioterrorism: Terrorism using biological weapons such as bacteria or viruses.

Centers for Disease Control: Department of the U.S. government devoted to understanding and preventing the spread of infectious disease. Often referred to as the CDC.

However, it did not define rules for everybody to use when working with bacteria and viruses of different danger levels. Finally, in 1984, the Centers for Disease Control published a book, *Biosafety in Microbiological and Biomedical Laboratories*. The book described Biosafety Levels 1 through 4 and outlined what laboratories have to do for each level. Today, the four biosafety levels are standard around the world.

Current Issues

Since the terrorist attacks of September 2001, the United States has increased by over six times the amount of money it spends to defend against possible biological attacks. By 2003, it was spending more than six billion dollars a year to prepare for a bioterrorism event (terrorism using bacteria or viruses). Biosafety Level 4 laboratories are needed to study the agents that might be used in terrorism. In 2003, there were only four such laboratories in the United States. By 2006 there were five, and at least two more were being built.

People who live near places where Biosafety Level 4 laboratories might be built sometimes do not want them there. They fear that the laboratory might release the bacteria or viruses accidentally or that the laboratory could be attacked by terrorists, who would let the germs out. In 1996, a laboratory that was built for Biosafety Level 4 in Toronto, Canada, was almost finished when people in the city became worried about possible accidents. Because of their protests, the lab has never worked above Biosafety Level 2.

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[*See Also* **Vol. 3, Biological Weapons.**]

Cornstarch Packing Materials

Description

Cornstarch is a fine white powder derived from corn. It is usually used as a thickening agent and a binder in cooking. In some countries, cornstarch is also called corn flour.

Apart from its uses in kitchens, cornstarch is gaining popularity as a raw material for environmentally safe plastics. Scientists have successfully experimented with cornstarch to develop biodegradable packaging materials. Biodegradable objects naturally decompose, thus reducing environmental pollution. Compared to other raw materials used in packaging, cornstarch is cost effective and renewable.

Cornstarch, by itself, does not form strong, durable packaging material. Large amounts of starch make the material brittle. However, cornstarch can be mixed with softening compounds called plasticizers, some of which are biodegradable. Cornstarch packaging using biodegradable plasticizers is safe for making non-toxic toys and cosmetics.

Cornstarch is also used to make paper-based packing material, such as the corrugated sheets used to make cartons. Food trays and boxes used for packing ready-to-eat meals are being developed from starch-based slurries (a mud-like mixture). The hygroscopic (water-absorbing) nature of starch makes it an ideal component of the absorbent pads used for packing meat. Paperboard coated with modified starch may be a practical solution to packing fresh, unpasteurized fruit juices and other beverages.

Scientific Foundations

Polystyrene, a widely used packaging material, is difficult to recycle. When it is discarded, it does not decompose into simpler,

Biodegradable packing pebbles made from corn starch. © *Jim Sugar/Corbis.*

non-toxic elements. As a result, the need for an environmentally friendly, biodegradable packaging material arose.

Since most products made from natural ingredients are biodegradable, scientists have tried to develop plastics from natural materials. These plastics can offer the additional benefit of being made from renewable resources, like corn.

Cornstarch plastics have been found to be functionally the same as polystyrene. In addition, cornstarch packing dissolves in water and is environmentally friendly. It does not hold a static charge, making it safe for packing sensitive electronic equipments. Further, since it does not allow gases to pass through, it is an excellent barrier for moisture and oxygen—a requirement for safe food packaging. Derived from corn, cornstarch is a renewable resource and remains unaffected by the fluctuating prices of petroleum—the base for making conventional packing materials.

Development

In 1839, German pharmacist Eduard Simon accidentally discovered polystyrene. At the time, he was unable to correctly explain its forma-

Plastic Waste

Studies suggest that approximately thirty billion pounds (13.6 billion kilograms) of non-degradable plastic waste is generated annually in the United States. Packed tightly into a trash-can the size of an American football field, the super-sized trash-can would need to be three miles (nearly five kilometers) tall!

tion. It was almost a century and several experiments later that Hermann Staudinger (1881–1965), a German chemist, provided the explanation for conversion of styrene into polystyrene. He showed that heating styrene transforms it into a larger molecule, called polystyrene. Polystyrene in its pure form is rigid; this makes it ideal for products like CD jewel cases and molded packing. Polystyrene is also used to manufacture disposable glasses, cups, lids, and other utility items.

Gradually, researchers developed expanded and extruded polystyrene. Expanded polystyrene (EPS) is used to make disposable coffee cups. A poor conductor of electricity, EPS is also used as insulation in buildings. In addition, EPS is ideal for making models and shock-absorbing molded packing of fragile products.

Extruded polystyrene (XPS), popularly known by its brand name Styrofoam®, was first used in 1970 for packing "peanuts." Styrofoam is also used in food trays and boxes used to pack carryout meals. The characteristic qualities of polystyrene, EPS, and Styrofoam made them the preferred ingredients for manufacturing packaging material.

By the late twentieth century, polystyrene, EPS, and Styrofoam, along with another polymer—polyethylene, the raw material for plastic bags—revolutionized packaging technology. However, with increased use, it became clear that the disposal of such material was going to create problems. People began to realize the negative effects of polystyrene on the environment. As mentioned earlier, polystyrene does not decompose into non-toxic elements after disposal, raising serious concerns about pollution.

As a result, scientists began to search for environmentally friendly alternatives to plastics. This research led to the development of biodegradable plastics that can be made from natural as well as synthetic (artificially made) ingredients. The advantage of using natural ingredients is that they are renewable. Synthetic ingredients

The Greening of the 2000 Sydney Olympics

All food stalls at the 2000 Summer Olympics held in Sydney, Australia, were required to use packaging that was either biodegradable or recyclable. As a result, about seventy-five percent of 660 tons (600 metric tons) of garbage generated each day was kept out of landfills. Most of it was composted, gradually broken down by soil bacteria and other organisms.

for making packaging material are typically petroleum-based and petroleum is a non-renewable resource. Soon, researchers discovered a way to use cornstarch in producing packing material. Apart from being environmentally friendly, cornstarch is safe for the human body, unlike some petroleum-based materials.

Current Issues

Packing material made from cornstarch and petroleum-based ingredients is not entirely biodegradable. Only the starch part of this material decomposes, while the petroleum-based portion may add toxins to the environment. A completely green plastic would either break down completely into non-toxic components or, if portions of it do not degrade, those portions would remain non-toxic or inactive.

Although biodegradable packing material is considered a significant step towards keeping the Earth healthy, several types of biodegradable plastics take a long time to decompose. For a packing material to be truly environmentally friendly it must decompose quickly. Researchers are currently working on this problem.

Unfortunately, the manufacture of completely biodegradable plastics (bioplastics) and packing materials from cornstarch is expensive. This requires consumers to pay more for such products and can pose an obstacle to their wider use. Many scientists, however, believe that the environmental benefits of bioplastics offset the higher cost of such materials.

Non-biodegradable plastics are a common feature of modern life. Many things that people use each day are either made of petroleum-based plastics or have some plastic component. Experts state that it will require a great deal of effort from consumers and industries to bring about a shift in favor of cornstarch-based packing solutions.

Words to Know

Biodegradable: Able to be broken down by natural processes.

Hygroscopic: A compound which has a tendency to absorb water molecules.

Plasticizer: Substances added to plastics to make them flexible.

Plastics: A group of natural or synthetic polymers that are capable of being softened and molded by heat and pressure; also sometimes used to include other structural materials, films, and fibers.

Polystyrene: A type of rigid plastic used for making CD jewel cases, disposable cutlery, and other plastic objects that need to be stiff.

Styrofoam: The brand name for specially treated polystyrene commonly used to manufacture packing peanuts and food packaging material.

Toxic: Something that is poisonous and that can cause illness or death.

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[*See Also* **Vol. 3, Biodegradable Packaging and Products; Vol. 3, Bioplastics.**]

Cosmetics

Description

Cosmetics are items used for cleaning and beautification without causing any physical or functional change in the body. Creams, lotions, soaps, perfumes, lipsticks, and powders are examples of cosmetics. Key ingredients of all cosmetics include fragrances and preservatives to extend shelf life.

Biotechnology has contributed to the development of cosmetic products in a variety of ways. Scientific research has helped develop materials and techniques designed to maintain youthfulness for longer periods of time.

Scientific Foundations

Companies manufacture cosmetics for different skin types. Skin type is determined by an individual's cellular activity. People with oily skin, for instance, have overactive oil-producing cells. Cleansers for oily skin contain substances that act as oil solvents and are effective at cleaning the pores of the skin.

Moisturizers, designed to reduce skin dryness, typically use skin-friendly substances, such as milk. The skin cells absorb the active ingredient of the product to produce the softening effects. Certain chemical peels used as anti-wrinkle agents effectively remove the upper dead cell layers of the skin, thereby leaving it smooth and erasing fine lines. Most cosmetics work in similar ways, either by being absorbed by skin cells or by removing dead skin cells.

Development

Cosmetics are probably as old as the human race. For a long time, cosmetics were used for medicinal purposes as well as for

Blocks of lanolin, a natural oil from sheep, being used in the factory production of cosmetics. *Maximilian Stock Ltd./Photo Researchers, Inc.*

enhancing the appearance. By 4000 BCE, the Egyptians were using sheep fat to make a cream intended to paint eyebrows. They used a distillation process to extract various oils from plants. These oils were used to keep the skin soft.

The ancient Japanese used rice paste for painting their faces white. With time, the rich started using expensive cosmetics to acquire fair, glowing skin, and such skin became a symbol of affluence. Although cosmetics have been used in several forms ever since, the cosmetics manufacturing industry is thought to have started in France and Italy in the fifteenth or sixteenth century. By this time, fragrances made from plant extracts and other natural ingredients were also being made.

However, it was only in the twentieth century that mass production of cosmetics began in the United States, and cosmetics became a global industry. The growth of the cosmetics industry was driven by the movies, especially color films, and movie stars. As actors became celebrities, ordinary people started wearing makeup to imitate their idols. Face powders, hair sprays, fragrances, tanning lotions, and other products became easily available.

During World War I (1914–18), women gained social and financial independence and this allowed them to spend more money on a variety of things, including cosmetics. The opening of dime stores (similar to dollar stores today) in the 1920s further boosted the cosmetic market.

The 1960s brought the natural look back in fashion and initiated a trend toward the use of natural ingredients in cosmetics. As environmentalism gained momentum in the 1970s, people started questioning the use of animals in testing the effects of cosmetics. Some countries, including the Netherlands and the United Kingdom, ban the testing of cosmetics on animals, and some cosmetic manufacturers have stopped the practice voluntarily.

Today's natural cosmetics are a legacy of earlier civilizations. Although they are marketed according to contemporary ideas of beauty, their ingredients are similar to those that were used in ancient times, as are the desired effects. The process of making certain cosmetics has been documented in historical manuscripts and recipes. The people who developed these recipes probably did not understand the science behind these products, but they saw the benefits of using such ingredients.

Current Issues

Biotechnology is opening new avenues of investigation in the cosmetics field. Leading cosmetics manufacturing companies are conducting innovative research. For example, scientists are investigating the use of nanosomes to increase the effect of pure vitamin E on the skin. Nanosomes are small spherical pouches that carry substances from one cell to another in the body.

Antioxidants, substances that protect cells from damaging effects of cellular reactions, are used extensively for anti-wrinkle treatment. Wrinkles are caused by damage to skin cells as a result of sun exposure and aging. Antioxidants help prevent some of this damage. Antioxidants have captured the public's attention and have been widely accepted by consumers. Green tea extracts, discovered to be rich in antioxidants, are now used extensively in a wide range of cosmetics from bath soaps to night creams.

The connective tissues of animals are also used in cosmetics. Bones, cartilage, and collagen are types of connective tissues.

Ancient Roman Cosmetic Unearthed

In 2004 archaeologists in London found a pot with a lid containing a Roman beauty cream. The pot has been dated to the middle of the second century CE. An analysis of the cream showed that it was made of refined animal fat (probably from a cow or sheep), starch, and tin oxide. Although the Romans had traditionally used lead acetate as the coloring agent in their face creams, this cream contained tin oxide, probably from the ancient Cornish tin industry in western England. Unlike lead, tin had the advantage of being non-toxic, and by this time the Romans had begun to realize the health risks of lead, which can include lead poisoning.

Scientists have taken the connective tissue of pigs and cows to make a liquid containing collagen, a substance that makes the skin elastic and protects it against wrinkles. The liquid is injected in targeted areas, such as lips, to instantly achieve a fuller appearance.

Although cosmetics are used widely, there are growing safety concerns. Many cosmetics, especially those that contain chemicals, are known to cause various side effects. Some cosmetics may also run a high risk of bacterial contamination. Consequently, countries have formulated laws governing the sale and monitoring of cosmetics. The U.S. Food and Drug Administration (FDA) has limited regulatory control of cosmetics sold in the United States. The FDA has no premarket approval authority and does not do premarket testing on cosmetics, but may take action if a cosmetic product is adulterated or misbranded in a way that adversely affects consumers. In the United States cosmetics manufacturers must meet certain safety guidelines before their products can be sold to consumers, but the firms themselves are ultimately responsible for the ingredients in and safety of their products.

Biotechnology has contributed to the development of cosmetics that not only beautify but that also have a medicinal action. Known as "cosmeceuticals," sunscreens, baldness treatments, and anti-dandruff shampoos are three examples. Although the term cosmeceutical is gaining popularity, the FDA does not recognize it and requires any product with the properties of a drug to be approved as a drug.

Words to Know

Antioxidant: A chemical compound that has the ability to prevent the oxidation of substances with which it is associated. Oxidation can damage cells.

Collagen: A type of protein that makes up connective tissue.

Vitamin E: Substance that occurs naturally in human beings and is responsible for maintaining youthful skin.

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[*See Also* **Vol. 1, Collagen Replacement.**]

DNA Computing

Description

Deoxyribonucleic acid (DNA) is the molecule that all living things use to pass on traits to their offspring. DNA stores information much like a computer's memory, and the resemblance between computers and DNA continues. Living cells contain chemicals that copy DNA and check for mistakes during copying. Computers also copy information and correct errors. There are also chemicals that hunt for certain pieces of information on DNA molecules and then snip them in half when they find them, like scissors cutting a ribbon.

By using various chemicals to cut DNA molecules at specific places, join them together again, copy them, and compare them, the same calculations that are done by an ordinary computer can be done using DNA and other molecules. In theory, a computer could be made that does all its calculations with millions of DNA molecules instead of millions of tiny on-off switches powered by electricity (which is how ordinary computers work). Scientists have been studying how to make DNA computers since the 1990s.

Each DNA molecule is shaped like a ladder that is twisted along its length like a stick of licorice. Each rung of the ladder is made of two parts that lock together in the middle. Each half of a rung is called a base; together, two locked-together halves (a complete rung) are called a base pair. There are only four kinds of bases in DNA, the four molecules called A, C, G, and T. Each locks together or pairs with only one other base: A pairs with T and C pairs with G.

In a electronic computer, information is stored in millions of switch-like devices that are turned either on or off. In DNA, information is stored in millions of As, Cs, Gs, and Ts. The As, Cs, Gs, and Ts running up one side of the ladder are matched by Ts, Gs, Cs, and As running up the other side. So, for example, if one side of a DNA molecule reads AATG, then the other side must read TTAC. Chemically, each side is a mirror image of the other. Both sides contain the same information.

The fact that every DNA molecule contains the same information twice over, once on each side of the ladder, is what makes it possible to copy DNA and therefore to compute with DNA. Certain chemicals can unzip the two halves of the DNA molecule, splitting all the base pairs down the middle. If this separation happens in a liquid that contains other, free-floating pieces of one-sided DNA, and if the code (say, AATG) of one of the floating bits happens to match up with the code of another piece (in this case, TTAC), then the two pieces will lock together to make a complete section of molecular ladder. When this happens, the two one-sided molecules are said to hybridize. It is as if they recognized each other. This is one of the properties of DNA that can be used for computing.

Scientific Foundations

DNA computers would not look like electronic computers. For one thing, they would be liquid—or at least, the part of the machine that did computations would have to contain liquid. The reason is that DNA molecules can only move about if they are floating in water. At room temperature, all the molecules in any container of water are moving about very quickly, bumping into each other. (That is the nature of heat—molecules in motion.) When two molecules that would like to bond together happen to bump into each other, they stick. So if two pieces of one-sided DNA that have matching series of bases bump together—say AATG and TTAC—they stick. If they don't match, they just bounce off. The motion of the molecules is random—there is no pattern to it—but way they join together is not. It follows strict rules.

Even a few drops of water can hold many billions of DNA and helper molecules. They are all bumping into each other many thousands of times per second, trying out every possible chemical combination. This is why DNA computers can work quickly—many reactions can happen at the same time. Computer scientists say that the reactions are happening "in parallel," that is, side by side. Tiny size and massive parallelism are what make the use of DNA attractive to computer designers.

The Injectable Computer

In 2004, scientists in Israel said that they had invented a simple model of a new kind of computer: a DNA computer that enters human body cells in order to test for diseases and then makes medicines to treat them, right on the spot. This doctor-in-a-cell will not be curing real patients any time soon, but the Israeli researchers proved that the basic idea can be made to work. Their DNA computer—actually a liquid mixture of DNA and other chemicals—would be injected into the body. Once inside the body's cells, it would look for defective DNA. If the DNA computer found defective DNA, it would produce new DNA to counter the effects of the defective DNA. It will be many years, however, before such chemical devices are ready to treat human patients—if ever.

Development

The DNA computer was invented by American computer scientist Leonard M. Adleman (1945–) in 1993. Adleman wanted to help doctors cure acquired immunodeficiency syndrome (AIDS), so he decided to learn more about the biology of cells. While reading about DNA, he was struck by the similarities between the way DNA behaves and an early imaginary computer called a Turing Machine.

The Turing Machine is an ideal computer named for the person who first described it, the British mathematician Alan Turing (1912–1954). It runs an endless tape through one side and reads off instructions; obeying the instructions, it writes characters on a second endless tape. It can go back and forth on the two tapes as much as it needs to. In theory, such a machine can solve almost any math problem.

Adleman noticed how close the idea of an endless tape is to a DNA molecule, and began to wonder if DNA molecules could be used to compute, and if a molecular Turing machine could be built. He solved a real mathematical problem using DNA molecules in 1994.

Adleman's early experiments took place in actual test tubes filled with water. All future DNA computers will also need to contain water, since water is what enables the molecules to move about and interact with each other, but the liquid may be present in small amounts. Thousands or millions of tiny droplets of fluid may be dotted over the surface of a small chip or tile of glass;

Words to Know

Base: One of the four chemical letters in the DNA code. There are four kinds, called A, C, G, and T (short for adenine, cytosine, guanine, and thymine).

Base pair: Two bases bonded together—either A with T, or C with G—to bridge the two spirals of a DNA molecule, much as a rung connects the two uprights of a ladder.

Hybridize: When two lengths of one-sided DNA molecule with mirror-matching codes lock or zip together to form a single piece of two-sided DNA, they are said to hybridize.

Parallelism: The performance by a computer, whether based on DNA or on electronic switches, of two or more calculations at the same time.

Turing machine: Imaginary general-purpose computer that reads instructions from one infinite tape, and writes output symbols on another. Named after its inventor, British mathematician Alan Turing (1912–1954).

because molecules are so small, each droplet would still contain thousands or millions of DNA molecules.

Current Issues

The value of a DNA computer is its small size and high speed. Molecules, even large molecules like DNA, are thousands of times smaller than the smallest electronic switches that scientists can make. Also, many billions of them can work on a problem at the same time. Yet DNA computers are still far from being a practical replacement for electronic computers. All DNA computers made so far are small, simple demonstration devices, not real general-purpose computers that can programmed to do a wide range of jobs. DNA computing is a young field. Basic ideas are still being worked out. Also, DNA computers are not the only kind of new computers that scientists are working on. It is possible that quantum computers, for example, will become practical before DNA computers do, and perform better for less money.

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[*See Also* **Vol. 1, Biochip; Vol. 3, Nanotechnology, Molecular.**]

E. coli

Description

Escherichia coli, or *E. coli*, is the name for a group of bacteria (one-celled germs that sometimes cause disease). They are probably best known for getting into food and making people sick, but they also serve a useful function in human intestines, where they aid digestion. *E. coli* are members of the bacterial family Enterobacteriaceae, or enteric bacteria. Enteric means related to the intestine.

Because they are well understood and multiply so quickly, *E. coli* have become very useful to scientists. These bacteria can be used as miniature factories to produce proteins (substances that are essential to the structure and function of human cells) from humans or animals in large quantities. These proteins can be used to make medicines and vaccines to treat people.

Scientific Foundations

Deoxyribonucleic acid (DNA) is the double-stranded chain of genetic information that is held in the nucleus of nearly every cell. DNA is made up of four chemical bases: guanine (G), thymine (T), cytosine (C), and adenine (A). The order of these bases makes up sequences, which are called genes. Genes contain a recipe or code for the production of specific proteins. Which proteins are produced determines which traits an organism will have, from its eye color to the diseases it might get. The entire set of genes in an organism is called its genome.

Genetic engineering involves taking a segment of DNA that codes for a certain protein out of one organism and putting it into the cells of another organism. The technique used to insert DNA from one organism into another is called recombinant DNA technology. The

Scanning electronic micrograph of *E. coli* bacteria. ©*Custom Medical Photo Stock, Inc.*

organism that receives the DNA will then be able to produce the protein from the other organism. When DNA from two different organisms are combined, the proteins produced are called recombinant proteins.

Development

In the late 1800s, a German doctor named Theodor Escherich (1857–1911) discovered *E. coli* bacteria in human intestines. The bacteria were named after him in 1919.

In 1973, two California scientists named Stanley Cohen (1935–) and Herbert Boyer (1936–) discovered that DNA could be taken from one organism and inserted into another organism with recombinant DNA technology. Scientists use genetically engineered *E. coli* as a medium for producing recombinant proteins. In 1978, insulin was the first protein to be made commercially using this technology. This recombinant insulin is used to treat diabetes, a disease caused by the inability to process blood sugar. By 2006, several dozen disease treatments were made using recombinant DNA technology.

Using *E. coli* to make insulin

Insulin is a very important hormone. It helps move sugars and starches from the bloodstream into the cells, where they can be used for energy. People who have a disease called diabetes either do not make enough insulin or do not use it properly. They need to take insulin every day to keep their blood sugar levels under control.

In the past, people with diabetes were often given insulin that was taken from animals. But sometimes their immune systems would recognize this insulin as foreign, leading to an immune reaction. In the late 1970s, scientists began using *E. coli* to produce insulin. The bacteria can produce recombinant insulin in large amounts. Because recombinant insulin is identical to human insulin, it does not cause an immune reaction in people who take it.

In the first step of this technology, scientists find and separate out the gene that codes for the protein they want from a human, animal, etc. *E. coli* carry some of their genetic information in circular pieces of DNA called plasmids. Scientists use special proteins called restriction enzymes to break apart the circular plasmid. Restriction enzymes act like scissors, cutting the plasmid at a specific sequence of bases. Then scientists insert the DNA that codes for the protein they want into the plasmid. It is glued into place using another type of enzyme (protein that speeds the rate of chemical reactions).

The plasmid is then inserted into the *E. coli*. The new gene causes the *E. coli* to produce the protein product of the gene. *E. coli* cells divide very quickly, making many copies of themselves. Each copy contains the new gene. *E. coli* works well for producing proteins because it is fast and it produces large quantities of proteins.

Current Issues

Genetically engineering organisms can lead to new treatments, which could save many lives. But since recombinant DNA technology was first discovered in the 1970s, there has been concern that genetically modified organisms could get into the environment. One of the worries is that the proteins and other products of genetically modified organisms might be dangerous to human health.

Words to Know

Diabetes: A disease in which the body cannot make or properly use the hormone, insulin.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Enteric: Involving the intestinal tract or relating to the intestines.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Genetic engineering: The manipulation of genetic material to produce specific results in an organism.

Genome: A complete set of the DNA for a species.

Insulin: A substance made by the body (or by genetically engineered bacteria) that the body needs to regulate the amount of sugar in the blood.

Plasmid: A circular piece of DNA that exists outside of the bacterial chromosome and copies itself independently. Scientists often use bacterial plasmids in genetic engineering to carry genes into other organisms.

Protein: Complex molecules that cells use to form most of the structures and control chemical reactions within a cell.

Recombinant DNA technology: A technique for cutting and splicing together DNA from different sources.

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[*See Also* **Vol. 1, DNA Sequencing; Vol. 1, DNA Vaccines; Vol. 1, Gene Therapy; Vol. 2, Genetic Engineering; Vol. 2, Genetically Engineered Animals; Vol. 2, Genetically Modified Organisms; Vol. 1, Insulin, Recombinant Human; Vol. 2, Recombinant DNA technology.**]

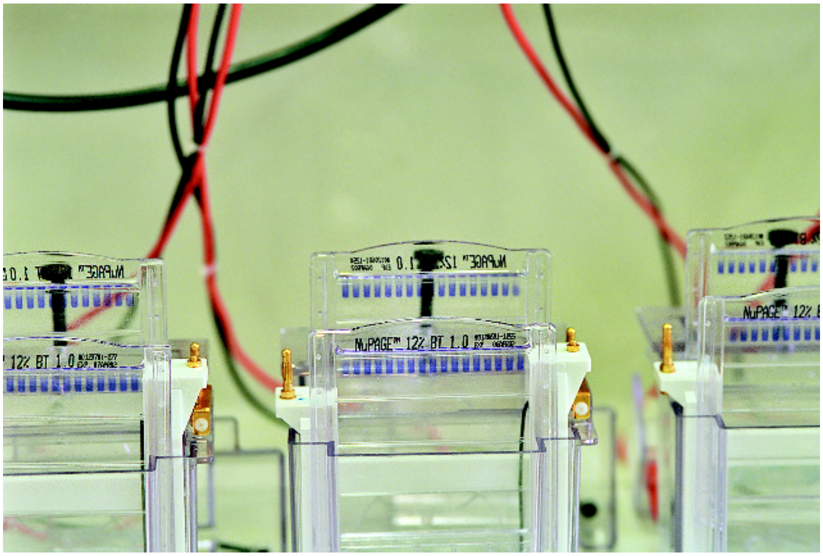
Electrophoresis

Description

Molecules are clusters of atoms. While some molecules have only two atoms, the largest have millions. Chemists and biologists often need to sort mixtures of heavy and light molecules—to separate the molecules of different weights—to learn more about them. Using electricity to do this sorting is called electrophoresis (pronounced ee-lek-tro-for-EE-sis). The word comes from *electro,* for electricity and *phoresis,* from the Greek word meaning "being carried." In electrophoresis, an electric field pulls a mixture of heavy and light molecules away from a starting place. The light molecules move away from the heavy molecules like a group of fast runners pulling ahead of a group of slow runners.

Electrophoresis is used wherever large, complex molecules are studied. For example, it is used to separate pieces of DNA of different lengths. Deoxyribonucleic acid (DNA) is a molecule that stores information in living things. Almost all living cells contain DNA; red blood cells, which do not reproduce, are one exception. Each DNA molecule is like a long tape or string of letters (actually small molecules) printed in a line along the tape. The DNA of every living thing has a different message, like a recipe or blueprint for that creature. To understand how life works, scientists must be able to read the chemical messages in pieces of DNA. Reading DNA is called DNA sequencing. DNA sequencing depends on electrophoresis.

DNA sequencing is basic to modern biology. It has been used to better understand how plants and animals have evolved from each other and is being used every day to design hundreds of new drugs and other medical treatments.



Electrophoresis units in a laboratory. © *Vo Trung Dung/CORBIS SYGMA.*

Scientific Foundations

Electrophoresis can work because large, complex molecules can have electrical charges. All atoms contain particles with electrical charges. (Opposite charges attract; like charges tend to push apart or repel.) Usually, an atom has equal numbers of positive and negative charges. Such an atom is said to be neutral. A neutral atom neither pushes nor pulls on a nearby positive or negative charge. If a molecule is made entirely of neutral atoms, the molecule is neutral too.

However, an atom can lose one or more negatively charged particles (electrons), or gain extra electrons. In either case, the atom is called on ion (pronounced EYE-on). If a molecule has a positive or negative charge (too few or too many electrons to balance its positive particles) then the molecule is said to be charged or to have a charge.

These charges create electric fields. It is the electric field made by a charged particle that pushes or pulls on other charges. When a charged molecule is placed in an electric field, it is pushed one way or the other depending on whether its charge is positive or negative. In electrophoresis, charged proteins or pieces of DNA, all having the same charge, are placed in a wide, straight electric field. The field pulls them all in the same directions. In the most common kind of electrophoresis, which is called gel electrophoresis, the molecules are placed in a thick, clear liquid called gel. The gel is like a mass of tangled nets whose strands are made of long, string-like molecules.

Not Guilty

If someone is accused of a crime, and if any cells have been left by the criminal at the scene of the crime, electrophoresis often makes it possible to tell whether the accused person is guilty. The chemical message in DNA can be read (sequenced) using electrophoresis helped by other tools. Since each person's DNA is unique (except for identical twins, triplets, and the like), someone accused of a crime is innocent if their DNA does not match the DNA found at the crime scene. Reading someone's DNA is called DNA fingerprinting. DNA fingerprinting has proved that many people sentenced to death for crimes such as murder were, in fact, innocent. Several groups called Innocence Projects have been started at law and journalism schools in the United States to clear innocent death-row prisoners of their crimes. The most famous Innocence Project was founded at the Benjamin N. Cardozo School of Law at Yeshiva University, New York City, in 1992. This group has proved that over 180 death-row prisoners were innocent, mostly using DNA evidence.

Larger molecules have more trouble getting through the tangled molecules and move more slowly. The larger molecules get left behind as the mixture travels through the gel. If there are molecules of several different weights in the mixture, they take up different positions in the gel, making a series of separate dots or stripes. Each stripe is a molecule of a different weight.

Development

Swedish chemist Arne Tiselius (1902–1971) invented electrophoresis in the 1920s and 1930s, in connection with his work on sorting proteins. (The nature of DNA was not known until the 1950s.) He was awarded the Nobel Prize for Chemistry in 1948. The Nobel Prize is the world's highest honor in any scientific field, and is awarded for Physics, Chemistry, and several other subjects.

In the 1940s and 1950s, several new methods of electrophoresis were developed. These methods—zone electrophoresis, isoelectric focusing, and isotachophoresis—enabled chemists to sort larger, more complex molecules with greater speed and precision.

Early electrophoresis methods forced charged molecules to move through a liquid or through paper, but these did not work well. Liquid tends to move, and molecules tend to stick to the fibers in paper. In the late 1950s, gels were invented that solved these problems. Today, narrow tubes called capillaries or flat dishes of gel are usually used for electrophoresis.

Words to Know

Electric field: An invisible physical influence that exerts a force on an electric charge. All electric charges produce electric fields. Magnetic fields that are changing (getting weaker or stronger) also produce electric fields.

Electrophoresis: Separation of nucleic acid or protein molecules in an electric field.

Gel electrophoresis: A laboratory test that separates molecules based on their size, shape, or electrical charge.

Ion: An atom or molecule which has acquired electrical charge by either losing electrons (positively charged ion) or gaining electrons (negatively charged ion).

Current Issues

The basic problems of electrophoresis were solved decades ago, producing a powerful tool that has changed our knowledge of the world. Today, electrophoresis is commonplace in laboratories. In fact, it is not one method but a large family of related methods. Rather than basic breakthroughs, progress is being made in the technical details of electrophoresis methods.

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[*See Also* **Vol. 1, DNA Fingerprinting; Vol. 1, DNA Sequencing.**]

Enzymes, Industrial

Description

Enzymes are substances that speed chemical reactions occurring in living organisms. These chemical reactions control all the functions of the body, and enzymes play a vital role. In the absence of appropriate enzymes, reactions slow down and negatively affect a living system. For example, the human digestive system maintains energy levels by breaking down food into forms easily absorbed and distributed by blood. Helping in the digestion process are gut enzymes such as trypsin and pepsin that act on complex proteins to convert them into simple sugars—molecules that are easy to absorb.

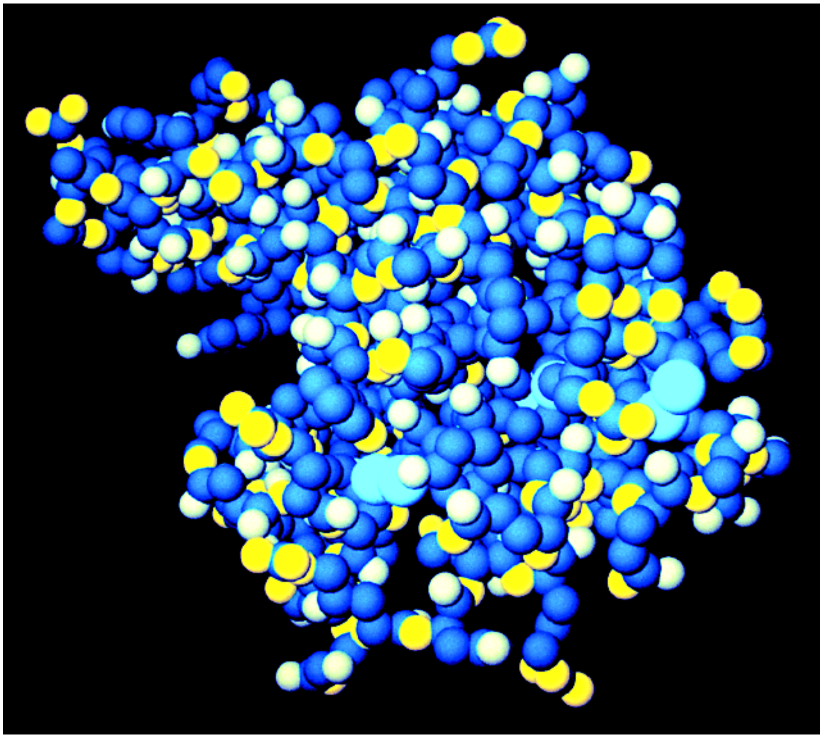
Apart from body functions, enzymes also have industrial uses. Known as industrial enzymes, these are used in manufacturing detergents, baby foods, fruit juices, baking products, and several other products. Enzymes function as catalysts, meaning they speed up chemical reactions.

Scientific Foundations

Enzymes have complex three-dimensional structures and are built to react with specific chemicals. An enzyme and its substrate, the substance on which the enzyme acts, follow the lock and key model. A lock can open only with its key. Similarly, an enzyme functions only with its respective substrate. This is attributed in part to the three-dimensional structure of enzymes.

Enzymes are heat-sensitive. High temperatures destroy enzymes and the reaction they produce. However, they are not destroyed during the chemical reaction they speed up and are recovered at the end of the reaction.

Enzymes are classified and named depending on the type of reaction they catalyze or the substrate on which they act. For



Computer model of the structure of lysozyme, an enzyme used to slow bacteria growth. *Kenneth Edward/Biografx/Photo Researchers, Inc.*

instance, ligases are enzymes that help combine two molecules. Ligase is derived from the word ligation or "pasting together."

Development

Enzymes are used to manufacture many everyday products. Cheese, alcoholic drinks, and baked goods are some examples. The recipe for preparing these products has not changed much since humans started making them. Though people did not realize it then, enzymes were used in their preparation. At the time, such foods were prepared in small batches. These days, consumer demands for massive quantities make it necessary to amplify the basic process of preparation by using industrial enzymes.

History is full of instances of people consuming some form of alcoholic beverage. For centuries, bread was considered the staple diet of common people. Enzymes are mainly responsible for transforming dough into bread, or grape juice into wine, although that fact was unknown through much of human history. Only as recently as the late nineteenth century did humans started realizing the role of certain yeast components in the process called fermentation, which changes sugar into alcohol and carbon dioxide (the

Cheese-making in a factory using rennet, an enzyme used to clot and thicken milk. *Maximillian Stock Ltd./ Photo Researchers, Inc.*

gas used to make soda fizzy). These components, initially termed ferments, are known as enzymes in the modern era. Gradually, with advancements in science and technology, industrial uses of enzymes were discovered along with their purification methods.

In 1917 French chemical engineer Auguste Boidin and Belgian chemical engineer Jean Effront (1856–1931) used a bacterial enzyme to remove starch present in textiles. Until then, starch was removed either by using chemicals or by soaking textiles in water. In the 1960s, glucoamylase was introduced as an enzyme that converts starch into sugars. The use of glucoamylase has made it easier to prepare a purer form of glucose in higher quantities compared to the traditional processes prevalent at that time. The advantages of glucoamylase are so numerous that industrial glucose production has undergone a complete transformation since its introduction.

Industrial enzymes now find use in baking and brewing, as well as mass production of fruit juices, baby foods, sweeteners, and

Enzyme Used in Cheese-Making

Chymosin (also known as rennin, or rennet), the enzyme used to prepare cheese, is extracted from the stomachs of ruminating animals (those animals for which digestion is a two-step process, such as cows). However, only young ruminating animals produce rennin, while adults produce another enzyme called pepsin.

dairy products. Enzymes are abundantly used in textiles to improve their quality. In the leather industry, hides (animal skins) were earlier treated with a solution containing large amounts of pigeon droppings. Research showed that the droppings contain certain enzymes that act on animal skins and soften them. Since enzymes naturally occur in small amounts, very large quantities of pigeon droppings were required to sufficiently soften the hide, making the entire process extremely smelly and messy. Gradually, scientists successfully identified and extracted the enzymes involved in treating hides. The leather industry uses commercially available enzymes to manufacture good quality leather without enduring the mess and foul smell.

Lysozyme, an enzyme extracted from egg whites, is used in the dairy industry to prevent the growth of germs. Fungal, algal, and bacterial enzymes are used in production of steroids (chemical compounds responsible for maintaining body functions).

Enzymes are also used in the preparation of high-nutrient animal feed.

Current Issues

Some enzymes are used extensively for industrial purposes. Rye and sourdough bread become stale more quickly than other breads. Commercial enzymes are being used to improve the shelf life of both these breads so that they are safe to eat for longer periods of time.

Several organizations are exploring the use of enzymes to produce an environmentally friendly biofuel. Biofuels are liquid or gas fuels that are usually created from plant mass. Such biofuels can serve as renewable sources of energy; in other words, energy that cannot be exhausted.

Scientists are also exploring the use of enzymes to reduce pollution. Plastics, for instance, are not biodegradable, thus adding to the already high levels of pollution. To find a solution to this problem, scientists are busy investigating the development of biodegradable plastics with the help of enzymes.

Words to Know

Catalyze: To accelerate a chemical reaction without entering the reaction or being changed by it.

Fermentation: The process of breaking down sugar without oxygen into simpler substances, commonly alcohol and carbon dioxide.

Protein: Complex molecules that cells use to form most of the structures and control chemical reactions within a cell.

Substrate: The foundation material on which integrated circuits are built; usually made of silicon.

Three-dimensional: A visual representation in terms of height, width, and depth, as opposed to a ''flat'' image that represents only height and width.

Further, enzymes are being used to prevent terrorism. In the event of bioterrorism (terrorism spread by the use of dangerous chemicals), companies have developed enzymes to counter the harmful effects of an attack. These enzymes can easily be mixed with water and sprayed quickly to protect humans, animals, and plants against the harmful effects of chemicals.

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[*See Also* **Vol. 2, Biofuels, Liquid; Vol. 2, Bread-Making; Vol. 2, Cheese-Making; Vol. 3, Fermentation, Industrial; Vol. 2, Wine-Making.**]

Ethanol

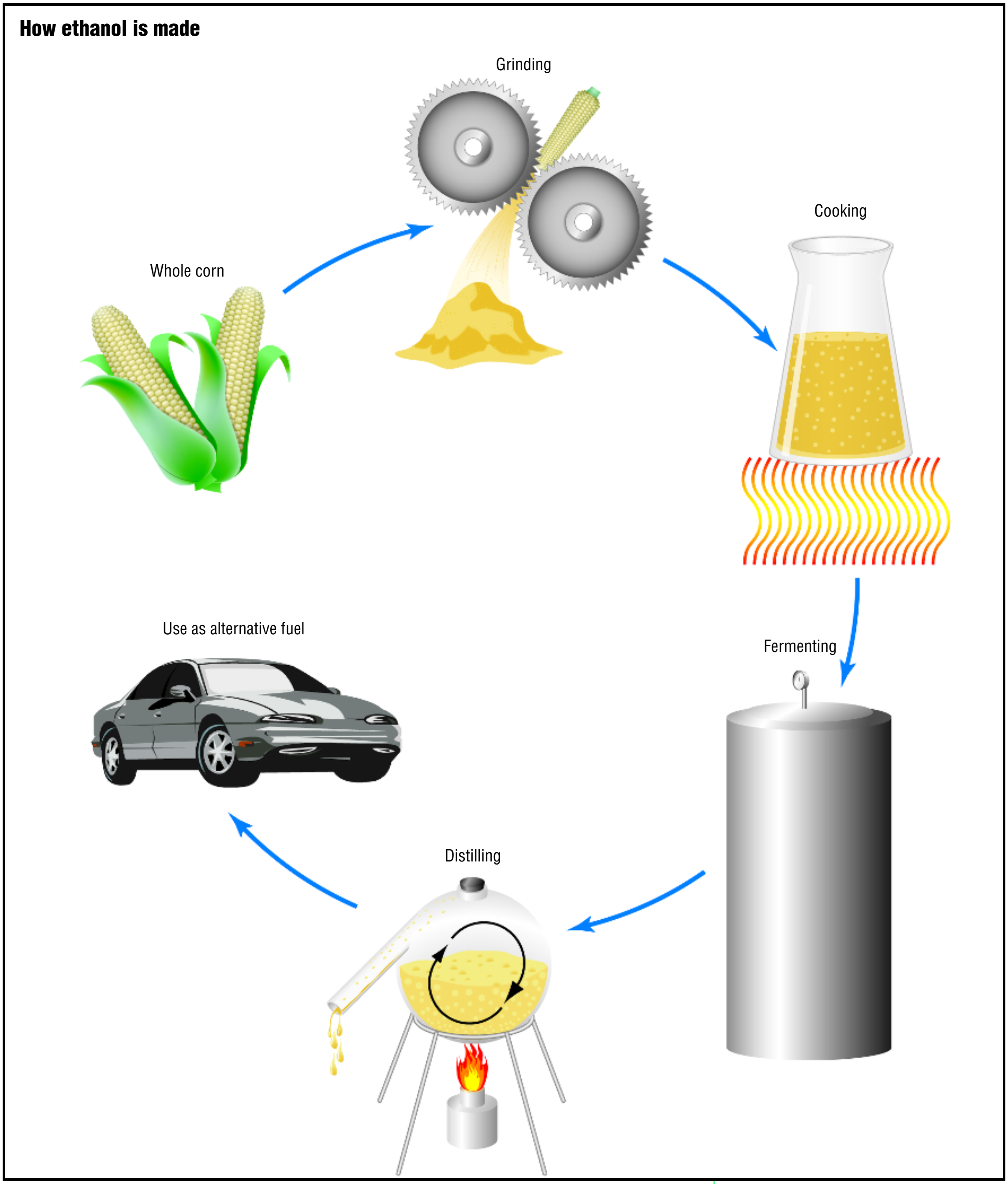
Description

Ethanol is a chemical made of carbon, hydrogen, and oxygen atoms. Each molecule of alcohol has two carbon atoms, six hydrogen atoms, and one oxygen atom.

Ethanol is also called ethyl alcohol, grain alcohol, or alcohol. It is the kind of alcohol that is found in beer, wine, and other alcoholic drinks. The other common kind of alcohol, which is a poisonous, is methyl alcohol. Ethanol is a clear liquid and burns well in its pure form.

Ethanol is used mostly as a drink and as a fuel. Alcohol for drinking is brewed by mixing sugars with water and adding yeast. (White table sugar is only one of the chemicals called sugars.) Yeast is a microscopic, single-celled fungus (related to mushrooms). In a mixture of sugar and water, yeast multiply, eating the sugar and producing as waste the gas carbon dioxide and ethanol. The same process is used to make bread. In bread-making, the carbon dioxide makes bubbles in the dough, causing the dough to rise, and the ethanol is driven off by the heat of baking. In brewing, the ethanol remains in the liquid. The carbon dioxide may be kept in the liquid also, in which case the drink becomes bubbly (as in the case of beer). If the carbon dioxide is allowed to escape, the drink becomes flat (as with most wine).

When making ethanol for fuel, yeast turn sugar and water into alcohol and water, just as in brewing. Then the mixture is heated. The alcohol turns from a liquid to a vapor (and back again) at a lower temperature than water, so it is driven off first when a mixture of alcohol and water is heated. It also turns back into drops of liquid first when the vapors are passed through a cool pipe. In this way, almost pure alcohol can be made out of a mixture of alcohol and water. This process is called


How ethanol is made
Grinding
Cooking
Whole corn
Fermenting
Use as alternative fuel
Distilling

To make ethanol, whole corn is put through a grinder. The pieces are cooked to break them down, then fermented. Ethanol is distilled from the mixture. *Illustration by GGS Inc.*

Ethanol storage tanks in Brazil. © *Paolo Whitaker/ Reuters/Corbis.*

distillation. Distillation is also used to make some alcoholic drinks stronger.

Ethanol burns well. When mixed with gasoline, it helps the gasoline burn better in engines. Engines can also run on pure ethanol or methanol, and some racecar engines and experimental cars already do. Ethanol also is used in some industrial processes and as a cleanser. A mixture of about two-thirds alcohol and one-third water is used to kill germs in hospitals and clinics.

Not all ethanol is made by yeast. Ethanol is also made from petroleum (a carbon-based fossil oil) by first producing the chemical ethylene and then turning the ethylene into ethanol using acids and water.

The Ethanol 500

The Indy Racing League is the group that runs the annual Indianapolis 500 race, in which specially built cars race at high speed for 500 miles. Indy racecar engines have been running on methanol (methyl alcohol) since the 1960s. In 2005, the Indy Racing League announced that all its cars would be required to run on pure ethanol starting in 2007. According to the Indy Racing League, ethanol produces less pollution and helps engines produce more power by allowing their cylinders to compress fuel vapor more before the vapor explodes.

Scientific Foundations

Ethanol burns, like other fuels, by combining with oxygen. When ethanol burns in air, which is mostly oxygen and nitrogen, it produces heat, water, and compounds of nitrogen and oxygen. The compounds of nitrogen and oxygen are pollutants. Ethanol burns more cleanly than many other fuels, but it is not a perfectly clean fuel.

Many government dollars have gone into making ethanol a practical fuel for cars and trucks. One reason people want to do this is that the carbon in the plants that are used to make ethanol comes from the air. When the ethanol burns, the carbon goes back to the air (in the form of carbon dioxide gas). This carbon moves in a loop or cycle: there is no increase in the amount of carbon in the air. Burning fossil fuels like coal and gasoline, on the other hand, adds to the total amount of carbon in the air. This is important because over the past 200 years, the burning of fossil fuels has increased the amount of carbon dioxide in the air by one-third. Carbon dioxide traps heat in Earth's atmosphere like the glass panes of a greenhouse, and so it is called a greenhouse gas. Greenhouse gases are changing the world's weather. The polar icecaps may melt, flooding coastlines, and certain crops may stop growing in some places. Ethanol may be one way to have fuel for cars while adding less carbon dioxide to the air.

Development

Alcohol was the first chemical produced by the humans. Pottery left by ancient peoples show that humans have been brewing alcohol for at least 9,000 years. Alcohol, although an addictive drug for some people, is also woven into the social customs of many societies and even the ceremonies of several religions, including Christianity.

Ethanol was first distilled in a nearly pure form by Arab chemists during the Middle Ages. Its chemical formula was discovered in the

Words to Know

Carbon dioxide: A heavy, colorless gas that dissolves in water.

Cellulosic fermentation: The production of ethanol by the fermentation of cellulose rather than of starches and sugars.

Ethanol: A form of alcohol.

Methanol: An alcohol, used as an antifreeze, fuel, or solvent.

Yeast: A microorganism of the fungus family that promotes alcoholic fermentation, and is also used as a leavening (an agent that makes dough rise) in baking.

early 1800s. Today, there are almost 100 large factories in the United States producing ethanol for fuel and other non-food purposes. They make about four billion gallons of ethanol every year.

Current Issues

Critics of the proposal to burn more ethanol and less gasoline argue that ethanol is not really as friendly to the environment as it looks because its ingredients are farmed in a destructive way. For instance, most ethanol in the United States is made from corn, but most corn farming is completely dependent on fossil fuels. In 2004, about twelve percent of the American corn crop was used to make ethanol. In the United States, corn is grown on large industrial farms, and about one cubic yard of soil is washed away to grow each cubic yard of corn. This soil cannot be replaced. When the soil becomes too thin, farmland must be abandoned.

At best, the U.S. government estimates, about 130 units of energy are obtained from ethanol for every 100 units of fuel energy used to grow the plants and process them into ethanol. Burning alcohol made from petroleum produces no extra energy at all.

A possible answer to this problem is the use of cellulosic fermentation. Cellulose is the substance in plants that makes their stems and leaves stiff. Paper is made from plant cellulose. All plants produce much more cellulose than sugars, but yeast cannot digest cellulose. Although scientists have been working on this problem for decades, until recently, there has been no way to turn cellulose into ethanol. That may be changing. In 2004, the world's first cellulose-into-ethanol plant opened in Canada. Only time will tell whether or not cellulosic fermentation can make ethanol a more truly environmentally friendly fuel.

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[*See Also* **Vol. 2, Beer-Making; Vol. 2, Biofuels, Liquid; Vol. 2, Wine-Making.**]

Explosives, Bioremediation of

Description

Soil and sediment can become contaminated with explosives, especially in areas where wars have occurred. Contamination of soil and sediment can also happen at military installations and civilian facilities where explosives are made or stored. Bioremediation is a natural treatment that is often used to remove explosives from soil and sediment and clean up contaminated land. Bioremediation uses biological agents, especially bacteria (one-celled germs) and other microorganisms, that eat harmful contaminants such as explosives.

The two main types of bioremediation to eliminate explosives from land are windrow composting and bioslurry. Generally, composting is the use of naturally occurring microorganisms to decompose organic wastes. It is often used to recycle household waste in compost piles. Windrow composting is a type of composting that combines soil and compost in long piles called windrows. Manure, grasses, and other agricultural byproducts are added to the soil, and then, levels of moisture, oxygen, and temperature are controlled to make sure the contaminants decay at the best possible rate.

The United States military began using windrow composting for the bioremediation of its military sites after it became the first biological treatment process approved for the decontamination of explosives. For instance, windrow composting was used to clean up explosives that had contaminated the Umatilla Army Depot in Oregon. After windrow composting was completed, levels of TNT (trinitrotoluene, a yellow flammable crystalline compound), RDX (a white, crystalline solid called cyclonite and hexogen), and HMX (a colorless solid called octogen) had been reduced by almost 100 percent.

A worker near equipment used to compost soil contaminated with explosives waste from the Cold War era. *AP Images.*

Bioslurry, or soil slurry biotreatment, is used when additional control is needed and more decontamination is required, or when bringing in compost materials is too costly. The contaminated materials are mixed into a slurry (a mud-like mixture) so that contact is made between the microorganisms and the contaminants. Bioslurry is used either with the addition of oxygen (aerobic) or without oxygen (anaerobic).

Scientific Foundations

Bioremediation uses microorganisms to remove pollutants from soils, liquids, and gases. A microorganism (sometimes called a microbe) is any single-celled organism that is so tiny it can be seen only with the use of a microscope. One of the most commonly used microorganisms in bioremediation is bacteria. The microorganisms use chemicals called enzymes to biodegrade pollutants. Biodegrading is the process by which a material breaks down quickly and safely into its elementary components. Biodegradable substances can be solid materials that break down into the soil, liquids that break down into water, and gases that break down in the air. The natural process of biodegrading is often used by humans for the treatment of agricultural, industrial, and municipal waste. Several biodegrading stages are usually used. A different microorganism is generally used in each step to break down a specific toxic (poisonous) substance into a nontoxic substance.

Bioremediation Treats Army Depot

The first use of bioremediation of soil contaminated with explosives occurred in 1997 at the Umatilla Army Depot Activity near Hermiston, Oregon. Explosive materials left in lagoons contained high levels of TNT and other explosive contaminants. Cow and chicken manure, potatoes, sawdust, alfalfa, and other agricultural wastes were added to the contaminated soil. The biological process was sped up with special equipment that turned the soil. The U.S. Army Corps of Engineers stated that almost 5,000 cubic yards (3,823 cubic meters) of soil was successfully treated. In the end, measurements could not detect any explosives in the soil. In addition, Army scientists estimated that it saved more than $2.6 million by using bioremediation over non-biological methods.

Development

In the 1830s, synthesized (artificially created) compounds with explosive properties were first developed. TNT became the most commonly used explosive during World War I. Other explosives were invented during World War II. In the 1980s, health and environmental concerns were raised around the world about explosives stored and disposed over the previous 150 years. Scientific studies of explosives verified their harmful effects. In the United States, for instance, about 1.2 million tons (1.1 millions metric tons) of soil at former military facilities had been contaminated with TNT. During the 1990s, the cleanup of areas contaminated by explosives became a public health concern in many industrialized countries.

Before the 2000s, open burning, open detonation, and burial-and-incineration were the most effective ways to remove explosives from soil. However, these methods also harmed the environment and were disliked by environmental organizations. Instead, these groups preferred bioremediation because it does not itself damage the environment. In addition, it is often the least expensive way to destroy explosive contaminants.

The development of methods of bioremediation is still ongoing in the early 2000s. Several research facilities around the world, including the Institute of Biotechnology at the University of Cambridge in England and the U.S. Department of Defense, have been working on the use of bioremediation to solve the problem of soil and sediment contaminated with explosives.

Words to Know

Bacterium: A single-celled microorganism that is often parasitic (singular of bacteria).

Enzyme: A protein that helps control the rate or speed of chemical reactions in the cell.

Microorganism: An organism too small to be seen without a microscope, such as a virus or bacterium.

Sediment: Soil and rock particles that wash off land surfaces and flow with water and gravity toward the sea. On the sea floor, sediment can build up into thick layers. When it compresses under its weight, sedimentary rock is formed.

Current Issues

The bioremediation of explosives is an inexpensive way to treat contaminated soil. In addition, it is a method that is environmentally friendly because it uses naturally occurring microorganisms. The environmental community accepts bioremediation as a safe way to remove explosives from soil. With its simple way of destroying explosives, it usually costs less than non-biological methods, such as incineration (burning).

Although the bioremediation of explosives is effective and inexpensive to use, the process used in bioremediation is not completely understood by scientists. Research into the fundamentals behind bioremediation is still ongoing. Due to regulatory requirements enacted by such countries as the United States, England, and Canada, bioremediation is currently the most accepted way to remove explosives from contaminated soil.

Because the U.S. federal government requires the cleanup of explosive-contaminated areas, many organizations are trying to understand the science behind bioremediation and to find the most effective and inexpensive ways to use bioremediation technologies. One such organization is the U.S. Army Environmental Center. Its scientists are researching and developing methods of bioremediation to eliminate explosive compounds from the soil.

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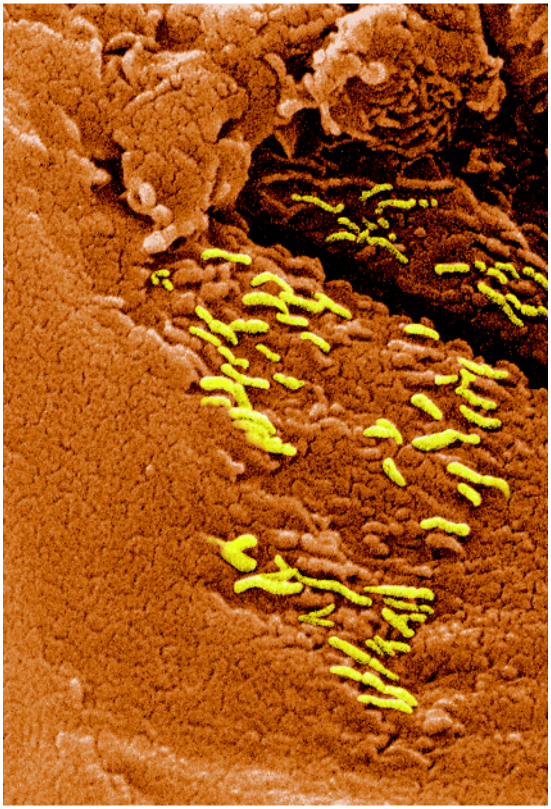
[*See Also* **Vol. 3, Bioremediation; Vol. 2, Compost/Organic Fertilizers; Vol. 3, Enzymes, Industrial.**]



Computer view of a meteorite from Mars. Scientists continue to study whether the yellowish shapes were created by bacteria-like organisms that may have existed on Mars, or if they arise from contamination by Earth-dwelling organisms. *NASA/Photo Researchers, Inc.*

Extraterrestrial Biotechnology

Description

Anything that is from a planet other than Earth is called extraterrestrial. Biotechnology is the building of machines that have to do with life. Therefore, extraterrestrial biotechnology is the building of machines to look for life on planets other than Earth.

There are several ways of looking for alien life. One is to send astronauts and/or spacecraft to other planets and test their water, soil, and rocks for microorganisms—living things too small to see with the naked eye. This can only be done on planets and moons within our own solar system, because all other solar systems are too far away for spacecraft to travel.

A second way to seek alien life is to study the light coming from planets circling distant stars using Earth-based telescopes. Different chemicals reflect light differently. By looking at the type of light reflected by a far-away planet—its spectrum—astronomers can tell which chemicals are in its air. Some chemicals exist on Earth only because there is life here. For example, oxygen in the form of ozone (O_3, three oxygen atoms bound together as a molecule) is found in Earth's air in fairly large amounts only because green plants have made lots of free oxygen (O_2, two oxygen atoms). Sunlight turns some O_2 into O_3. Astronomers look for O_3 because its spectrum is easy to observe. Seeing a large amount of O_3 in a planet's atmosphere would be proof of a large amount of O_2, which would be strong evidence for life. Another chemical that would show that another planet has life is chlorophyll, the chemical that makes planets green.

However, planets around other stars are so far away that we cannot yet separate their light from the light of their stars. It is like holding a candle up to the Sun and trying to stare at the candle; the Sun's light is too strong is see the candle's light separately. But astronomers have been able to see some large planets around distant stars with sensitive telescopes in the last few years, and in the near future they may be able to study the light from smaller, more Earth-like planets. Then we may find out whether some of them have life.

A third way to look for alien life is to study rocks that have come from other planets. Some rocks have already come to Earth from Mars. They were blasted free when Mars was struck by large meteorites many millions of years ago. The rocks wandered through space and a few of them ended up falling to Earth as meteorites. Some landed in Antarctica, where they are easy to see lying on the ice. Scientists can be sure that a meteorite is from Mars by looking at what types of atoms it contains.

In 1996, scientists with the U.S. National Aeronautics and Space Administration (NASA) announced that they had found tiny fossils in meteorites from Mars—proof that there is microscopic life on that planet. However, many scientists were not convinced. They thought it more likely that the marks had been made by non-living causes. Scientists are still studying the Martian rocks and still do not agree whether they contain proof of life on Mars. Most scientists think they do not.

Ocean in the Sky

Europa is one of the moons of Jupiter, the largest planet in the solar system. Although Europa is many times farther from the Sun than is Earth, scientists think there is a chance that life has evolved there. Although Europa's surface is bitterly cold, underneath its icy skin is a vast, salty ocean of water, kept liquid by gravitational squeezing or kneading by Jupiter and some of its other moons. Where there is liquid water, life may have evolved. Scientists hope to send a robot probe to Europa someday to look for life. For now, however, Mars is much cheaper to get to, so that is where the next life-seeking probes will go.

Scientific Foundations

One problem in the search for alien life is that we are not sure what it might look like. What, exactly, is life? If life on other planets does not use the same chemistry as life on Earth, the tests scientists usually use to look for life—looking for DNA, for example—will not work. A test might wrongly show that there is no life in a sample of alien soil that does contain life. However, scientists think it likely that life anywhere in the universe will use some of the same chemicals as life on Earth, especially chemicals made with the element carbon. Carbon can make a wider variety of large, complicated molecules than any other element, and life consists of large, complicated molecules. Scientists also believe that life needs liquid water to exist.

Development

So far, only two spacecraft have ever looked for life on another planet. In 1976, two spidery *Viking* spacecraft touched down on Mars. On board each lander was a chemical laboratory about the size of a car battery, packed with instruments. The laboratories were run by radio control from Earth. A shovel on the end of a robot arm collected soil and fed it to each laboratory, which did tests to see if there were any microorganisms in the soil. One test added some of the soil to a nutritious soup to see if anything grew. The scientists put a radioactive form of carbon (carbon 14) in the soup. They hoped that if anything ate the carbon, it would release some of it as waste in the form of a gas. If the soup started releasing radioactive gas, they reasoned, there would be life in it. This was called the labeled-release experiment.

Words to Know

Chlorophyll: Green pigment in a plant leaf that is involved in the process of photosynthesis.

Extraterrestrial: Beyond Earth.

Ozone: A gas made up of three atoms of oxygen. Pale blue in color, it is a pollutant in the lower atmosphere, but essential for the survival of life on Earth's surface when found in the upper atmosphere because it blocks dangerous ultraviolet solar radiation.

The *Viking* labeled-release experiment did show that when Martian dirt was added to the soup it gave off gas with carbon 14 in it. But other *Viking* instruments designed to look for signs of life did not find any. Although a few scientists still believe that the labeled-release experiment found Martian life, most do not. Only future missions to Mars can settle the question once and for all.

Current Issues

Today, both the United States and the European Space Agency are building robot probes to look for life on Mars again. The new life-seeking instruments that will go to Mars are much better than the *Viking* instruments of over thirty years ago. Several new ways of testing for life have been invented since then. One is called fluorescence (pronounced flor-ESS-ens) imaging. In fluorescence imaging, a special type of bright light is flashed on soil or rocks. Chemicals that are usually found only in living things—proteins, lipids, amino acids, carbohydrates—are forced to glow briefly by the flash. A camera then looks for light from these life chemicals. Another tool, already being built by European scientists, is the Life Marker Chip. The Life Marker Chip is a tiny biological laboratory on a small, square computer chip that will look for life molecules by seeing if they combine with molecules on the chip. A robot carrying the Life Marker Chip is supposed to go to Mars in 2011.

Astronomers are working on larger, more powerful telescopes that may be able to study the light from Earth-like planets around distant stars. Someday soon it may be possible to tell whether there is life on some distant planets by studying the light they reflect.

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[*See Also* **Vol. 1, Biochip.**]

Fermentation, Industrial

Description

Fermentation is a process in which organisms, such as bacteria or yeast (a single-celled organism in the Fungi family), break down sugars and starches to make alcohol or other end products. Industrial fermentation is based on the same idea, but the end product is created on a much larger scale. Industries use fermentation to make products ranging from food additives and antibiotics (medicines used to treat bacterial infection) to beverages and nutraceuticals (foods that show health or medical benefits beyond their traditional nutritional value).

Scientific Foundations

Fermentation involves the breakdown of more complex substances into simpler ones. It is a chemical change that produces energy, usually in the absence of oxygen. Bacteria and other microorganisms (an organism that is too small to see without a microscope) break apart sugar molecules for energy. In the process, they release a waste product, such as alcohol. Fermentation is often used to describe the conversion of sugar to alcohol by yeast. This process is used to make beer and wine. Manufacturers also use fermentation to make food additives, chemical compounds, and antibiotics.

Scientists can genetically engineer bacteria and other microorganisms to cause them to produce substances that they would not be able to produce naturally. DNA (deoxyribonucleic acid) is the molecule of hereditary material contained in nearly every living cell. Genes are segments of DNA that contains a recipe, or code, for cells to produce substances called proteins, which control cell functions. Genetic engineering involves taking a gene from one organism and putting it into the cells of another organism. The organism that receives the DNA will then be able to produce the

Industrial fermentation tanks growing genetically engineered microorganisms in cultures. *National Audubon Society Collection/ Photo Researchers.*

protein product of the gene. When DNA from two different organisms is combined, the proteins produced are called recombinant proteins. The technique used to insert DNA from one organism into another is called recombinant DNA technology.

Development

Fermentation was first used to make alcoholic beverages as far back in history as the time of the ancient Egyptians. In the early twentieth century, the chemical industry started using fermentation to make solvents (a substance that can dissolve another substance), such as ethanol and acetone (which was used during World War I). Later in the century, drug companies began using the process to make vitamins and medicines.

The industrial fermentation process starts with bacteria or other microorganisms. These microorganisms are chosen because of their ability to produce certain proteins. Or, they may have been genetically engineered with genes from humans or animals that enable them to produce these substances. The microorganisms are put in a big vat called a fermenter, which contains water and the raw materials (sugars or starches) needed for fermentation to occur. Manufacturers control

Penicillin and the Growth of Industrial Fermentation

Today's use of industrial fermentation to produce antibiotics, vitamins, and other pharmaceutical products all stems from a discovery made back in the early twentieth century. In 1928, a Scottish microbiologist named Alexander Fleming (1881–1955) was working on a treatment for bacterial infections at St. Mary's Hospital in London. He went on vacation, and when he returned, he found a strange-looking mold growing on his culture dishes. Even stranger was the fact that the mold had killed the bacteria he was studying. Fleming named the mold penicillin, and today this antibiotic is used to treat bacterial infections. A few years after Fleming's discovery, scientists Howard Florey (1898–1968), Ernst Chain (1906–1972), and Norman Heatley (1911–2004) at Oxford University determined how to isolate, purify, and produce penicillin in large quantities. Their discoveries paved the way for today's industrial fermentation techniques.

the fermentation process very carefully so that the end product is exactly the same each time.

The main uses for industrial fermentation today are in the chemical, food processing, and pharmaceutical (related to medical drugs) industries. Products made by industrial fermentation include drugs, food additives, and laundry detergent. One example of a product made by industrial fermentation is the drug insulin, which helps the body use sugar. People who have diabetes either lack insulin or do not produce enough insulin. Scientists have genetically engineered bacteria with human genes so that they can produce insulin. The insulin that is produced by this method is then given as a medication to people who have diabetes, a disease in which the body has trouble processing blood sugar.

Current Issues

Fermentation is a relatively easy way to produce industrial products, such as drugs, on a large scale. No matter which organism is used, the process is always the same. Fermentation is often simpler than chemical synthesis (creating a chemical in the laboratory). It is a one-step process, and it occurs entirely within the microorganism. But to make industrial fermentation of a product worthwhile, it needs to be more efficient and cost-effective than other methods of manufacturing that product. Companies are experimenting with different methods to improve fermentation production speed.

Words to Know

Antibiotic: A compound produced by a microorganism that kills other microorganisms or retards their growth. Genes for antibiotic resistance are used as markers to indicate that successful gene transfer has occurred.

Bacteria: Microscopic organisms whose activities range from the development of disease to fermentation.

Enzyme: A protein that helps control the rate or speed of chemical reactions in the cell.

Fermentation: The process of breaking down sugar without oxygen into simpler substances, commonly alcohol and carbon dioxide.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Genetic engineering: The manipulation of genetic material to produce specific results in an organism.

Insulin: A substance made by the body (or by genetically engineered bacteria) that the body needs to regulate the amount of sugar in the blood.

Microorganism: An organism too small to be seen without a microscope, such as a virus or bacterium.

Pharmaceutical: A drug, medicine, or vaccine.

Recombinant DNA technology: A technique for cutting and splicing together DNA from different sources.

Recombinant proteins: Proteins that are produced when DNA from two different organisms is combined.

Solvent: A substance (usually liquid) that can dissolve another substance.

Yeast: A microorganism of the fungus family that promotes alcoholic fermentation, and is also used as a leavening (an agent that makes dough rise) in baking.

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[*See Also* **Vol. 1, Antibiotics, Biosynthesized; Vol. 2, Beer-Making; Vol. 2, Genetic Engineering; Vol. 2, Genetically Modified Organisms; Vol. 1, Insulin, Recombinant Human; Vol. 1, Penicillins; Vol. 2, Wine-Making; Vol. 2, Yogurt-Making.**]

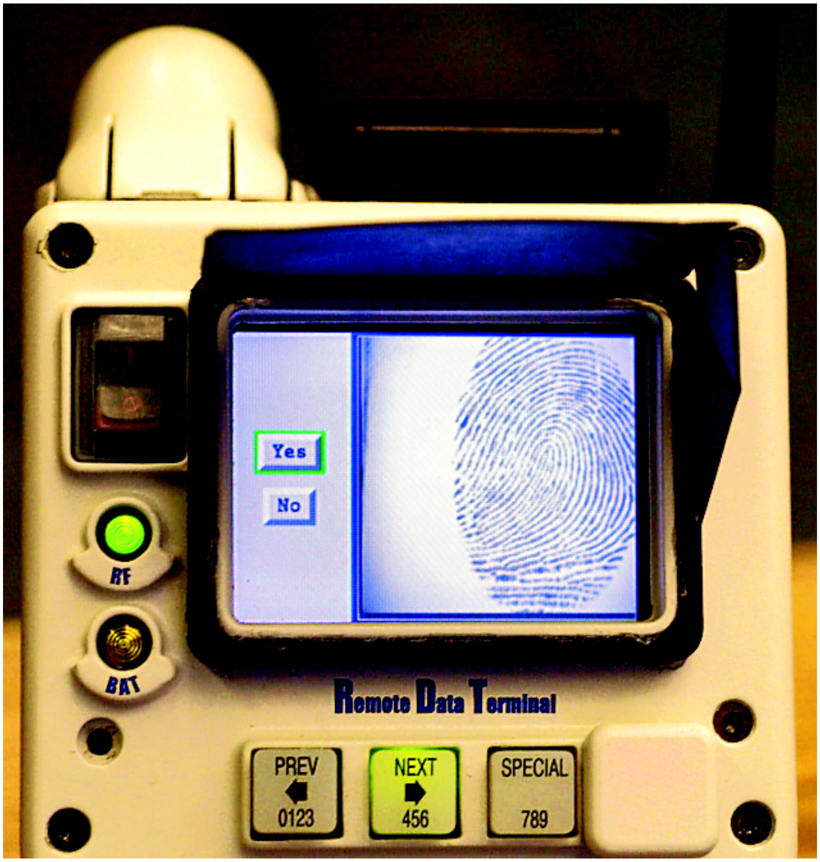
Fingerprint Technology

Description

Fingerprints are tiny, curved, and ridged formations of skin found near human fingertips. These formations are sometimes called dermal ridges. When pressing or rolling a finger dipped in ink or other substance onto a paper surface, a pattern remains from contact of the peaks of skin ridges and the paper's surface. The fingerprint, itself, is the pattern that is transferred to the paper from the finger. These patterns are unique to each human. In fact, even identical twins have different fingerprints. Fingerprints stay the same throughout a person's life.

Taking impressions of fingers for the purpose of identification is called fingerprinting. There are three types of fingerprints: visible, plastic, and latent. Visible prints are made when fingers press onto a surface with colored materials such as ink, paint, blood, or grease. Fingers touching a soft material such as putty, clay, soap, or wax form plastic prints. Latent prints are invisible prints made from the body's perspiration, greases, and oils. Because such prints cannot be seen, powders, chemicals, and lasers are used to make them visible.

Since fingerprints are different for each person, they are used to identify people, especially to identify criminals. For example, police officers search crime scenes for fingerprints while looking for clues to solve crimes. When fingerprints are found, human experts or computer systems determine whether two impressions came from the same finger (from one person) or whether they did not come from the same finger (from two people). When a match is proven, the process is called fingerprint authentication. The entire process of dealing with fingerprints is called fingerprint technology.



Fingerprint on a wireless fingerprint scanner, which can check the fingerprint against a computerized database in another location. *AP Wide World Photos.*

Today, members of law enforcement agencies digitally record fingerprints so they can be electronically compared with other fingerprints stored in large databases. When electronic devices scan and store digital fingerprint images, the process is called finger scanning or fingerprint scanning. The average fingerprint contains at least 150 characteristics that are analyzed. Between ten and sixteen characteristics are used to identify whether two fingerprints are identical or not.

Scientific Foundations

Fingerprints are classified into three groups based on their general pattern: loop, arch, or whorl. The characteristic that distinguishes them is the point where lines from three directions meet—what is called the delta.

A loop, as its name indicates, contains a loop pattern where lines come and go on the same side of the print. It has one delta. An arch

FBI's Integrated Automated Fingerprint Identification System

In the early part of the twentieth century, many fingerprint databases had been setup in the United States without proper coordination. Consequently, the U.S. Federal Bureau of Identification (FBI) created a central agency to coordinate such activities. The Identification Division eventually became the Criminal Justice Information Services (CJIS) Division in the early 1990s. Today, the CJIS database contains about 250 million sets of fingerprints representing about 74 million individuals, the largest set of fingerprints in the world. These fingerprints are digitally stored using the FBI's Integrated Automated Fingerprint Identification System (IAFIS). By using IAFIS, the FBI can conduct searches of suspected criminals based on their fingerprints with results coming within a matter of a few hours or even several minutes.

has no loop pattern but contains lines that enter on one side of the print, rise into hills, and then leave on the other side. It does not have a delta. A whorl is a circle or spiral pattern that does not exit on either side of the print. It has two deltas. More specific classification methods further divide arch into such subgroups as plain and tented; loop into right and double; and whorl into plain, accidental, and double loop.

Development

Fingerprints were used to sign legal documents in ancient times. Czech physiologist Jan Evangelista Purkinje (1787–1869) is considered the first person to study fingerprints scientifically, and in 1823, he proposed a system for their classification.

The Scottish physician Henry Faulds (1843–1930) published a paper in 1880 in which he recommended that bloody finger impressions left on porous materials be used to identify criminals. Although English police rejected his idea, his work is considered the first attempt to use fingerprints to identify an individual. In response to Fauld's article, British civil servant Sir William Herschel (1833–1918) published a paper describing his use of fingerprints as official signatures for Indian pensioners. British scientist Sir Francis Galton (1822–1911) published a paper in 1892 that discussed fingerprint analysis and identification using the ten human fingers. His method is considered the basis for the modern fingerprint classification system.

In the 1890s, British police officer Sir Edward Richard Henry (1850–1931) and Indian police officers Azizul Haque and Hem

Words to Know

Database: A collection of data in a computer.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Digital: Information processed as encoded on or off data bits.

Chandra Bose developed a fingerprint classification system for Indian police departments. The three men, in 1901, helped to found the United Kingdom Fingerprint Bureau. Fingerprint identification quickly spread throughout Europe and North America. In 1902, fingerprinting was first used in the United States by the New York Civil Service. The beginning of the twentieth century is considered the start of modern fingerprint analysis.

During the twentieth century fingerprinting technology developed rapidly. Forensic experts discovered that any smooth, hard surface touched by human fingers contained fingerprints. Such prints left on surfaces, called latent prints, were dusted with powder or chemically treated to discover the fingerprint pattern. The pattern was photographed and stored for future identification. By the ends of the twentieth century, it was possible to digitally record latent prints and send them to other law enforcement agencies anywhere in the world.

Current Issues

Fingerprint technology is considered almost 100 percent reliable. In the United States, the federal government successfully processes tens of thousands of fingerprint identifications each day. However, two types of errors can occur. First, a false negative occurs when a latent print should have been identified but is not. Second, human errors sometimes happen when fingerprints are processed. Increasingly, technology and internal and external reviews minimize the likelihood of such errors. The FBI makes about one latent fingerprint identification error every eleven years.

Fingerprint technology is considered very reliable evidence and a valuable tool for the law enforcement community worldwide. However, fingerprint technology may become less important as a crime-fighting tool as DNA profiling becomes more popular. Sometimes popularly called DNA fingerprinting, it is a more accurate method of identification. In DNA (or deoxyribonucleic acid) profiling, samples of DNA taken from the blood, hair, or other material of two individuals are compared. No two people (except for identical twins) have exactly the same DNA profile. (In DNA profiling, only tiny segments of a person's DNA are actually analyzed because most DNA is the same in all humans.) DNA profiling is accepted by most courts as evidence for establishing paternity and increasingly is accepted as evidence in criminal trials.

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[*See Also* **Vol. 3, Biometrics; Vol. 1, DNA Fingerprinting; Vol. 1, DNA Sequencing; Vol. 1, Forensic DNA Testing.**]

Fuel Cell Technology

Description

The ability to produce an electrochemical reaction in which air (oxygen) and fuel (usually pure hydrogen) combine to make electricity and water is called fuel cell technology. Fuel cells continue to produce electricity as long as oxygen and hydrogen are available. There are many types of fuel cells, but they all use oxygen and fuel to make electricity, water, and waste heat.

Generally, a single fuel cell is a piece of plastic between two carbon plates layered between two end-plates acting as electrodes (conducting points for electricity). Fuel cells are used to power motor vehicles, computers, cell phones, and many more products. The heat that is a byproduct of fuel cell technology is sometimes used to warm houses and other buildings.

Scientific Foundations

The structure of the fuel cell consists of a stack made of individual cells. Each cell has a positive electrode (cathode) and a negative electrode (anode). The chemical reactions that produce electricity occur at the electrodes. The fuel cell also has an electrolyte (a liquid that conducts electricity) that sends electrically charged particles from one electrode to the other. In addition, fuel cells contain a catalyst (usually made from platinum) that speeds up the reactions at the electrodes.

Development

In 1839, Welsh scientist William Grove (1811–1898) invented the fuel cell. From the work of British scientists William Nicholson (1753–1815) and Anthony Carlisle (1768–1840), Grove knew that

Fuel Cell Bus
Aldgate St Paul's Holborn
Oxford Circus
25
ESQ64991
LK53 MBD
BUS

A zero-emission hydrogen fuel cell bus in London, England. © *Toby Melville/ Reuters/Corbis.*

sending an electric current through water separates it into hydrogen and oxygen. Grove decided to reverse the reaction. He made two platinum electrodes with one end of each electrode sunk in a container of sulfuric acid and the other ends sealed in separate containers of hydrogen and oxygen. He discovered that electricity flowed between the electrodes.

Chemists Ludwig Mond (1839–1909) and Charles Langer (d. 1935) first used the name fuel cell in 1889 when they tried to make the first commercial fuel cell with air and coal gas. Around the beginning of the twentieth century, German chemist Friedrich Wilhelm Ostwald (1853–1932) developed the theory of fuel cells. However, most attempts to develop fuel cells stopped when the internal combustion engine was invented and successfully used.

Fuel Cells in Space

The National Aeronautics and Space Administration (NASA) developed fuel cell technology in the late 1950s to generate electricity during its space missions. In 1965, NASA launched *Gemini 5* with astronauts Gordon Cooper and Pete Conrad aboard. Due to the alkaline fuel cells, *Gemini 5* spent almost twice as long in space as any spacecraft had before—a new record that had just been set the mission before on *Gemini 4*. The mission lasted just 104 minutes short of eight days due to the new fuel cells onboard. The fuel cells aboard *Gemini 5* generated enough electricity to power the longer missions that were planned for the upcoming Apollo flights. The fuel cell technology aboard *Gemini 5* was important to eventually sending men to the Moon, landing on its surface, and returning them safely to Earth.

In 1932, British engineer Francis Bacon (1904–1992) began developing a fuel cell using alkaline electrolytes and nickel electrodes. In 1959, Bacon demonstrated a five-kilowatt system based on this fuel cell design that could power a welding machine. Bacon's fuel cell is considered the first commercially successful fuel cell. Also in 1959, American engineer Harry Ihrig ran a tractor using a twenty-horsepower (about fifteen-kilowatt) fuel cell.

Fuel cells were not used much until the National Space and Aeronautics Administration (NASA) employed fuel cells to power equipment in its *Gemini* and *Apollo* spacecraft between the 1960s and 1970s. NASA funded many research projects involving fuel cell technology. In the 1980s, the U.S. Navy began using fuel cells in their submarines. Today, fuel cells are used to operate buses and other public transportation vehicles in many cities around the world. Several federal and state agencies fund research in fuel cell technology.

Current Issues

Fuel cells have many advantages over traditional power sources. They do not cause pollution or produce dangerous byproducts—their only byproducts are water and heat. Since fuel cells do not use petroleum products, dependence on oil produced in foreign countries is not a concern.

In addition, hydrogen fuel can be made anywhere water and electricity are available. Fuel cells are more efficient than gasoline engines, and they operate more quietly. When fuel cell technology matures, it should achieve energy efficiencies of around 70 to 80

Words to Know

Anode: A positively charged electrode.

Biomass: Any biological material used to produce energy.

Catalyst: Any agent that accelerates a chemical reaction without entering the reaction or being changed by it.

Cathode: A negatively charged electrode.

Electrochemical: The study of chemical change involving electricity.

Electrode: A conductor by which electricity enters or leaves.

Electrolyte: A chemical compound that separates into ions (charged particles) in a solution and is then able to conduct electricity.

percent, when waste heat is utilized. In comparison, when electricity is produced by power plants, its efficiency is about 33 percent. Fuel cells also operate longer than batteries. Since fuel cells have no moving parts, only simple maintenance is needed. Additional stacks can be added to fuel cells when the power demand increases.

Fuel cells have disadvantages, too. There are problems with producing, transporting, distributing, and storing hydrogen. Currently, fuel cells are larger than batteries and engines. However, as technology advances, smaller fuel cells are becoming possible. Fuel cells are expensive to produce because most are made one at a time, and expensive ingredients are sometimes needed.

Fuel cell use has not grown rapidly because consumer demand has been weak in most areas of the economy. However, over the past few decades, interest in fuel cell technology has increased as fossil fuels become scarcer and their price increases. Major fuel cell markets include automobiles, spacecraft, homes and small office buildings, remote areas, and mobile commercial and military products.

The main issue with fuel cell technology is the production of hydrogen. In the future, hydrogen may be made with such nonpolluting and renewable methods as hydropower, solar power, and wind power, along with biomass fuels such as crop, animal, and municipal wastes. However, hydrogen is currently made by removing it from hydrocarbon fuels such as ethanol, gasoline, methanol, and natural gas. Such hydrocarbon fuels make pollution.

Most fuel cells cost between $1,500 to $4,500 per kilowatt of electrical power produced. This range depends on the type of fuel cell and its particular application. In comparison, a diesel engine costs between $800 and $1,500 per kilowatt. As fuel cell technology matures, costs should decline to well below $400 per kilowatt, and may even drop as low as $30 per kilowatt.

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[*See Also* **Vol. 2, Biofuels, Solid; Vol. 3, Ethanol.**]

Government Regulations

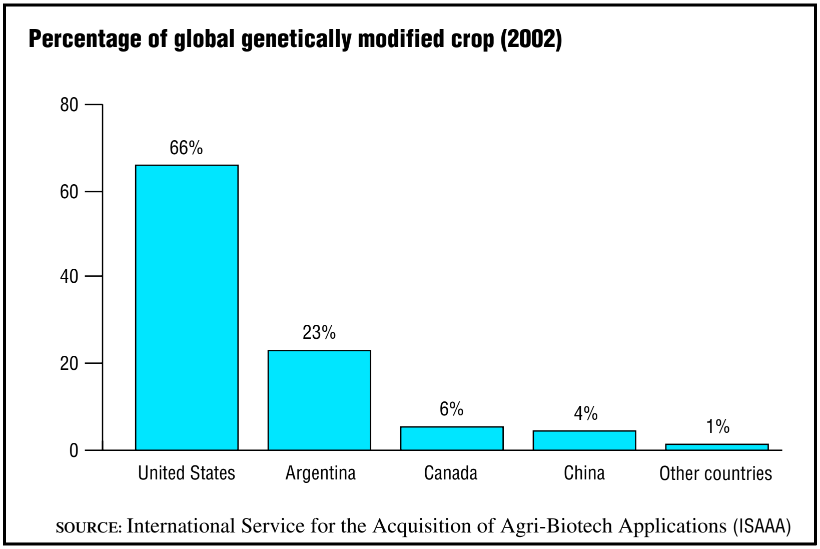
Description

Biotechnology products in the United States were first regulated by the federal government in 1986. At that time, the White House Office of Science and Technology Policy was created. Its ability to deal with biotechnology products came from existing laws that regulated the safety of food and agriculture.

In that same year, due to growing issues, the federal government developed the Coordinated Framework for Regulation of Biotechnology. It regulated biotechnology products according to their purpose and composition but not according to how they were produced. The Coordinated Framework was composed of regulations from existing health and safety laws. It was enacted specifically to make sure that biotechnology products were safe for the environment and human and animal health.

Since 1986, the federal government has written new regulations and policies and created new groups as additional biotechnology products were developed. For instance, in 1999, several advisory bodies were established to guide biotechnology organizations in developing their industry while minimizing the risks.

The primary federal agencies responsible for biotechnology products include the Animal and Plant Health Inspection Service (APHIS) of the United States Department of Agriculture (USDA), the U.S. Environmental Protection Agency (EPA), and the Department of Health and Human Services (DHHS) of the Food and Drug Administration (FDA). Each agency regulates research, development, and approval of biotechnology products. Their authority is provided through such regulations as: (USDA) The Eggs Products Inspection Act, Meat Inspection Act, Plant Protection Act, Poultry



SOURCE: International Service for the Acquisition of Agri-Biotech Applications (ISAAA)

The vast majority of genetically modified crops worldwide are grown in the United States and Argentina. This is due in part to regulatory differences among the governments of different countries. *Graph by GGS Inc.*

Products Inspection Act, and Virus Serum Toxin Act; (EPA) Federal Insecticide, Fungicide, and Rodenticide Act and Toxic Substances Control Act; (EPA and FDA) Dietary Supplement Health and Education Act and Food, Drug, and Cosmetics Act; (FDA) Public Health Service Act; (USDA, FDA, and EPA) National Environmental Protection Act.

Scientific Foundations

The FDA, USDA, and EPA regulate specific biotechnology products depending on various federal regulations. Many times these agencies and the regulations overlap. Regulated products for the FDA include animal feeds, cosmetics, foods and food additives, human and animal drugs, human vaccines, medical devices, and transgenic animals. The EPA regulates such products as microorganisms, plant pesticides, and toxic substances produced by animals. Among the regulated products for the USDA are animal vaccines, plants, and plant pests.

The FDA regulates food and drugs developed through biotechnology with respect to safety and nutrition. The EPA oversees the manufacture, sale, and use of plants altered for protection against insect pests in order to protect the environment, beneficial insects, and other living organisms. The APHIS-USDA controls the field-testing of biotechnology crops to assure the safety of agriculture from pests and diseases. Before any genetically modified (GM) product is moved, grown, or sold commercially, an organization must acquire proper APHIS status.

Flavr-Savr Tomatoes

The U.S. government regulatory system for GM food was first tested by the Flavr-Savr tomato made by Calgene. Designed to spoil less quickly after being picked, the tomato could be ripened on the vine longer in order to produce a more flavorful tomato. In 1991, Calgene requested FDA permission to introduce its tomato in the United States. Based on this tomato, the FDA issued its formal statement of policy in May 1992 that GM foods would be regulated the same way as conventional foods. Within three years of being introduced in the United States, the Flavr-Savr tomato was discontinued after problems occurred with development, transportation, and low tomato prices, along with a lawsuit by a competitor. Despite protests from activist groups, the Flavr-Savr tomato was popular with the American consumer.

Development

In 1975, scientists met to consider biotechnology. They discussed potential regulations involving biotechnology research and development. In 1978, the National Institutes of Health implemented Guidelines for Research with Genetically Engineered Organisms through its Recombinant DNA Advisory Committee (RAC). Later, individual Institutional Biosafety Committees handled the review and approval of biotechnology research. In June 1986, the federal government established the White House Office of Science and Technology Policy and the Coordinated Framework for Regulation of Biotechnology.

In June 1987, the USDA published “Introduction of Genetically Engineered Organisms” to permit field tests of GM organisms. Five months later, based on this rule, the USDA authorized the first field test of a GM organism: tobacco resistant to the herbicide (weedkiller) bromoxynil. In October 1988, the USDA established the Biotechnology, Biologics, and Environmental Protection to regulate biotechnology and other environmental programs. In May 1992, the FDA established its Statement of Policy: Foods Derived from New Plant Varieties.

In March 1993, the USDA published “Notification Procedures for the Introduction of Certain Regulated Articles,” which gave alternative requirements for field testing. At the same time, the USDA published “Petition for Nonregulated Status,” which gave certain GM plants the ability to be developed without regulation. In May 1997 the USDA enacted “Notification-Simplification of Requirements and

Words to Know

Bacterium: A single-celled microorganism that is often parasitic (singular of bacteria).

Herbicide: A chemical substance used to kill weeds or undesirable plants.

Organism: Any living thing.

Transgenic: A genetically engineered animal or plant that contains genes from another species.

Procedures for Genetically Engineered Organisms," which changed eligibility requirements for field testing. In 2000, the Plant Protection Act strengthened USDA authority to regulate plant health. The APHIS established, in 2001, the Biotechnology Policy Group to coordinate biotechnology policy. In August 2002, the USDA created the Biotechnology Regulatory Services to focus on regulating and advancing biotechnology.

Current Issues

Besides federal regulations, various state regulations have been enacted for biotechnology products. The federal regulations are stricter than any state regulations. The regulatory system in place in the middle of the first decade of the 2000s has functioned well. No adverse health effects have been confirmed from biotechnology products. However, consensus within the industry confirms that as more advanced products are developed, future revisions and additions to current regulations are needed. For instance, a National Academy of Sciences study in 2002 concluded that improved testing and assessment of GM crops will be necessary in the future.

Although federal and state governments regulate some aspects of biotechnology foods, many safety organizations believe that more should be done to evaluate the safety of such foods. For instance, the FDA does not decide whether a GM food is the same as traditionally made food. This reasoning comes from its 1992 decision that GM foods are equivalent to non-GM foods. Biotechnology developers are asked to voluntarily consult with the FDA before introducing a new biotechnology product. Some industrial and related organizations argue that a mandatory approval process is needed.

Concerns across the biotechnology industry include the proper labeling and preservation of identity of biotechnology products. Currently, policies around the world vary greatly. Issues in trading often occur due to, for example, different definitions of GM and non-GM foods.

Overall, U.S. regulations concerning biotechnology products have lagged behind research and development. In the rapidly developing industry of biotechnology, government regulations have so far been adequate, but many groups have growing concerns about their ability to regulate biotechnology products in the future.

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[*See Also* **Vol. 2, Agriculture; Vol. 1, Bioethics; Vol. 2, Tomato, Genetically Engineered.**]

Green Chemistry

Description

Green chemistry, also called sustainable chemistry, is the use of chemistry in ways that reduces or stops polluting to the environment and causing health risks to humans. Specifically, green chemistry tries to minimize the generation and use of hazardous (toxic) substances—or to recycle toxic substances that must be used—without hurting scientific and economic progress.

According to the philosophy of green chemistry, the designer and manufacturer are responsible for all the harm that might happen when something they design and manufacture is used by consumers. Consequently, companies often realize a new product or service is harmful before it is released—so that it can be replaced with a product or service that does not cause problems.

Companies spend many of millions of dollars to clean up environmental damage and to pay fines and legal fees for using hazardous chemicals. Many corporations are realizing that products that degrade the environment and cause health problems to people are bad for their profits and public images. Operating according to the principles of green chemistry, it is easier to remove the problem as the product is developed, rather than to deal with problems after it has been released.

Scientific Foundations

The Environmental Protection Agency (EPA) operates a Green Chemistry Program that is the basis for green chemistry in the United States. It is based on twelve principles of green chemistry, originally published in 1998 by Paul Anastas and John Warner in their book *Green Chemistry: Theory and Practice*.

The twelve principles are:

- Prevent waste rather than treat or clean it up.
- Design safer chemicals and products.
- Design less hazardous methods.
- Use renewable feedstock (such as agricultural products) rather than depleting feedstock (such as fossil fuels).
- Design chemicals and products that degrade after use.
- Use catalysts (which are used frequently and in small amounts), not stoichiometric reagents (which are used once and in large amounts).
- Minimize chemical derivatives that take additional steps to make and also produce waste.
- Use only needed materials (what is called atom economy because atoms not needed are not used).
- Design for increased energy efficiency.
- Use safer solvents and reaction conditions.
- Analyze before making products to prevent pollution.
- Minimize the potential for chemical accidents.

Developzment

Green chemistry was created in the 1980s to minimize the environmental problems and economic costs that sometimes occur with products and services. Governments of developed countries began making companies accountable for the products and services they introduce. Based on government regulations, companies are forced to clean up problems that they create with respect to such activities as chemical storage and disposal and environmental emissions.

In the United States, the use of green chemistry was widely accepted when first introduced within the Pollution Prevention Act of 1990. The act established federal policies to reduce or prevent pollution whenever possible. In addition, it added responsibilities to the EPA so that the agency could also develop strategies for new chemical products and services and improve existing ones. For example, the EPA's Office of Pollution Prevention and Toxics (OPPT) helps to develop products that are less hazardous to human health and the environment. The OPPT provides research grant programs, ongoing partnerships, and awards (such as the Presidential Green Chemistry Challenge), which help universities, industries, other government agencies, and non-governmental organizations to design and produce chemicals that reduce or prevent pollution. The

Green Tea and Green Chemistry

Green tea has been shown by some scientific studies to help treat or prevent some cancers. However, in the past, these studies have not always provided the information needed for the creation of reliable and effective products. Recently, however, the medical and manufacturing communities have teamed up to work on this problem. University of Massachusetts biology professor Susan Braunhut and Dr. Jayant Kumar, director of the Center of Advanced Materials, are developing a product to kill breast cancer cells without harming normal cells. The teams headed by Braunhut and Kumar have made good progress in modifying catechin, an active component of green tea, using principles learned from green chemistry.

EPA also supplies educational activities and developmental tools to various organizations around the world. Conferences and meetings are held often to discuss green chemistry.

Current Issues

Humans are responsible for many of the environmental problems that have occurred over the past 200 years. As the world grows industrially, such problems are increasing at alarming rates. Green chemistry deals with global issues such as climate change; management of water, soil, and air resources; and energy production and consumption. It also looks for solutions that benefit society and the environment, while not hurting business.

Green chemistry is being promoted around the world as a way to safeguard both the economy and the environment. In the past, a good economy meant that sacrifices were made with respect to the environment; or a healthy environment meant that business practices had to be controlled. The principles behind green chemistry state that technology can help both the economy and the environment.

Many technologies are already in existence that meet green chemistry objectives. However, many of these technologies are not yet cost effective. Green chemistry programs are offered at only a few U.S. universities and colleges. Additional efforts in research and development are needed in both the public and private sectors. These efforts should be combined with other green chemistry efforts around the world. Additional government incentives are needed to offset the costs for businesses to establish green chemistry policies and practices. Educational programs are also

Words to Know

Catalyst: Any agent that accelerates a chemical reaction without entering the reaction or being changed by it.

Feedstock: The source of starting material for a chemical reaction.

Pollution: An undesired substance that contaminates another system (air, ground, water, etc.).

Reagent: A chemical added to a suspect material to produce a known reaction response. If the reaction response is observed as expected the identity of the material is assumed to be known.

Stoichiometry: Deals with determining proportions of elements and compounds in chemical reactions.

needed to inform the public about the principles, goals, and advantages of green chemistry.

Many environmental organizations do not think companies are really reducing pollution in their products. Some environmentalists imply that companies are using green chemistry as an advertising gimmick. They state that most products degrade the environment, with only a few products actually being produced with green chemistry. Some environmentalists insist safer products exist, but companies do not introduce them because they are not as profitable. Others disagree, saying that governments have sometimes banned dangerous products only to find safer products do not exist to replace them.

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[*See Also* **Vol. 3, Biodegradable Packaging and Products; Vol. 3, Biodegradable Packaging and Products; Vol. 1, Bioethics; Vol. 2, Biofuels, Liquid.**]

High-Fructose Corn Syrup

Description

High-fructose corn syrup (HFCS) is a sweet liquid made from corn. It is used to sweeten beverages, baked goods, jams and jellies, ice cream, and many other processed foods.

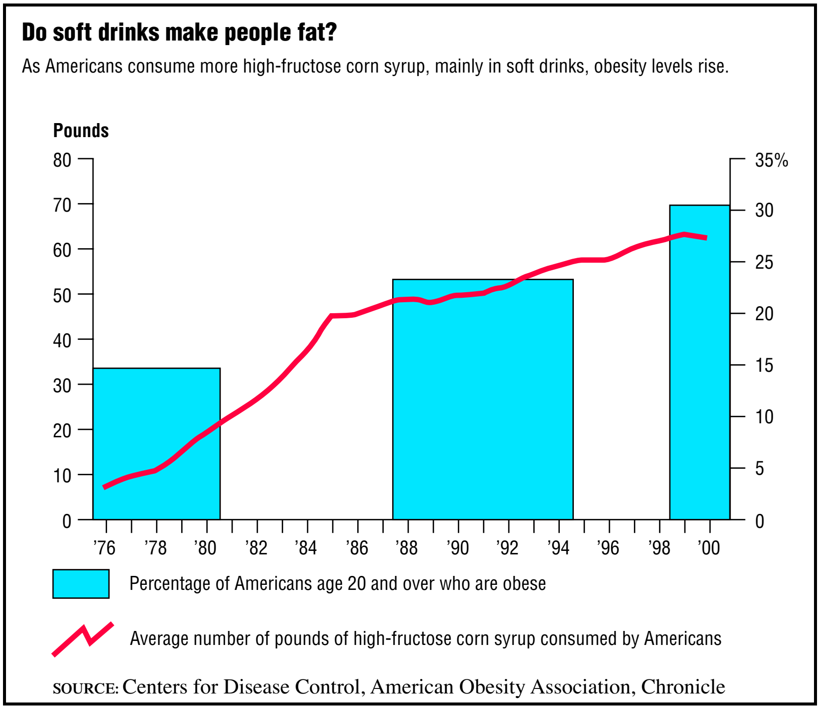
High-fructose corn syrup is also a preservative, meaning it helps food stay fresh longer. Meats such as hot dogs, ham, bacon, and packaged chicken products can also contain some amount of high-fructose corn syrup. The additive may also be found in ketchup, mustard, and salad dressings.

Fructose is a simple sugar that is naturally found in honey, berries, melons, apples, pears, sweet potatoes, and even onions. It is a simple sugar, or monosaccharide. High-fructose corn syrup contains this sugar. But instead of occurring naturally, the syrup must be made through a chemical process.

Scientific foundations

High-fructose corn syrup is named according to how much fructose it actually contains. HCFS-55 contains 55 percent fructose and 45 percent dextrose. According to the Corn Refiners' Association, HCFS-55 is just as sweet as table sugar. By the mid-1980s, this type of high-fructose corn syrup was the most popular sweetener found in soft drinks.

HFCS-42 contains 42 percent fructose. This product is often found in canned foods and non-carbonated fruit drinks. On rare occasions, a super-sweet blend of HFCS called 90-HFCS (90 percent fructose) is sometimes added to diet (low-calorie) foods to make them taste better.



SOURCE: Centers for Disease Control, American Obesity Association, Chronicle

Graph showing increasing rates of obesity and consumption of high-fructose corn syrup. Although there is a correlation, drinking soft drinks cannot be scientifically proven to cause obesity. *Illustration by GGS Inc.*

When high-fructose corn syrup was first introduced, some scientists were concerned that it might not be safe. In 1988, the United States Food and Drug Administration (FDA) ruled that HFCS-55 and HFCS-42 were "generally recognized as safe" and could still be made and sold.

The introduction of high fructose corn syrup in the early 1970s dramatically changed the food and beverage industry. The inexpensive sweetener led to a flood of packaged snacks and other convenience foods. Soon high-fructose corn syrup began to replace table sugar in many products. By the middle of the 1990s, table sugar sales dropped as the popularity and usage of high-fructose corn syrup continued to rise. In fact, consumption of high fructose corn syrup rose 1,000 percent between 1970 and 1990, according to a report in the *American Journal of Clinical Nutrition*. By the beginning of the twenty-first century, Americans were eating more high-fructose corn syrup than table sugar. Today, the United States produces more high-fructose corn syrup than any other country in the world.

Development

In the 1970s, employees at the Clinton Corn Processing Company in Clinton, Iowa, learned how to get fructose out of the

Fructose Intolerance

People who lack a substance called aldolase B cannot absorb fructose in the correct manner. This condition is called fructose intolerance. People with this condition who eat only a tiny amount of fructose can have a sudden drop in blood sugar. This is called hypoglycemia, or low blood sugar. Fructose intolerance can be mild or a very severe. In severe cases, a person can have liver damage, convulsions, or go into a coma.

People with fructose intolerance must eat a diet free of fructose. Because fructose is found in many grocery items, this diet can be difficult to follow.

natural form of sugar (glucose) found in corn. They turned white powdery corn starch into a clear, sweet syrup. The syrup was easier and less expensive to make than table sugar (sucrose), and much sweeter. Food and beverage manufacturers soon began adding this artificial corn syrup to their products, instead of using table sugar, which costs more.

Food companies liked the syrup because it did not turn hard or form crystals, like others sugars can. Because high-fructose corn syrup stays moist, snacks like cookies can be made soft and chewy. Another benefit of the sweet syrup was that is stayed sweet and did not lose any flavor even when stored in places where the temperature changed.

Current Issues

The effect of high-fructose corn syrup on a person's health is not fully understood, but has been a subject of much debate. Studies suggest that the rate of obesity in United States has risen along with increases in the sweetener's usage. A 2004 report by the Center for Food and Nutrition Policy at Virginia Tech University, however, said there was no compelling evidence that the syrup contributed to obesity.

The syrup has also been linked to an increase in diabetes as well as increased triglyceride (a type of cholesterol that contributes to heart disease) levels in the blood. Eating excessive amounts of fructose may also lead to high cholesterol and stomachaches. How a person's body actually uses fructose depends on many things, including the individual's overall health and diet.

Medical researchers say the problem has to do with how the body breaks down (metabolizes) fructose. Fructose encourages fat formation more efficiently than any other type of sugar. Some

Words to Know

Dextrose: A naturally occurring form of glucose. Also one of the two main sugars found in honey.

Glucose: A simple sugar that exists in plant and animal tissue. When it occurs in blood, it is known as blood sugar.

Insulin: A substance made by the body (or by genetically engineered bacteria) that the body needs to regulate the amount of sugar in the blood.

scientists think that fructose does not make a person' appetite feel satisfied after eating as well as other sugars do. These scientists assume that this effect happens because fructose does not cause the body to step up production of the chemicals (hormones) that control hunger pains. Very early studies on animals have shown that people who eat a lot of fructose have problems controlling their blood pressure, blood sugar (glucose), and blood insulin (a chemical in the blood that regulates blood sugar) levels. Together, this combination of problems can lead to metabolic syndrome, one of the leading risk factors for obesity. It is important to note that small amounts of fructose found naturally in fruits and vegetables normally do not hurt a person's health. Instead, some researchers say, it is the large amount of fructose consumed in processed foods and beverages that may cause mild stomach problems even in healthy people, and more serious health effects in those who have existing health problems or those who do not otherwise eat well or exercise.

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Laundry Detergents

Description

Biotechnology has been beneficial for improving the cleaning power of laundry detergent through the modification of an enzyme called subtilisin. The modification increases the resistance of the enzyme to the potent oxidization (combining with oxygen) that takes place during cleaning of clothes.

The biotechnological enhancement of subtilisin enables the enzyme to perform its natural degradation of a variety of substances that commonly stain clothing—the enzyme separates them into their primary components, causing their removal from the clothing. Subtilisin is a good example of the potential of biotechnology to benefit everyday life.

Scientific Foundations

The use of biotechnology in the formulation of a more potent laundry detergent focuses on enzymes. Enzymes are chemicals that function as catalysts—they speed up chemical reactions without themselves being altered by the reaction. A type of enzyme that is relevant in laundry detergents are proteases—enzymes that specifically degrade proteins. Proteins are substances that are the main components of living cells, including plants and animals. Therefore, most food stains are protein-based.

In a variety of processes that treat material, including cotton and polyester, the protease called subtilisin is especially important. Subtilisin is produced by a bacterium (singular of bacteria, one-celled germs) called *Bacillus subtilus*. The enzyme is an ingredient of many formulations of laundry detergent because of its ability to degrade a variety of proteins.

33%
extra FREE
TESCO
Bio
Brilliant whites and outstanding stain removal
FREE mini tennis LESSONS
ARIEL
Non-Bio
Persil
colour care
fresher fragrance

A selection of biological detergents that clean with the power of enzymes, instead of harsh chemicals. *Cordelia Molloy/Photo Researchers, Inc.*

Enzymes have complex three-dimensional structures made up of chains of smaller chemicals called amino acids. Due to their structure, enzymes are built to react with specific chemicals. An enzyme and its substrate, the substance on which the enzyme acts, follow the lock and key model. A lock can open only with its key. Similarly, an enzyme functions only with its respective substrate.

The critical domain in subtilisin that is responsible for the degradation of proteins is an amino acid called methionine, which is located near one end of the enzyme. This is the site where the enzyme binds (attaches) to the protein stain, initiating the protein's degradation.

Unfortunately, the methionine residue is also susceptible to damage caused by a chemical reaction resulting in a molecule's loss of an electron, which is called oxidation. Oxidation, such as occurs with the inclusion of bleach in the cleaning cycle of a washing machine, is an important reaction of a successful laundry detergent. Thus the addition of bleach to the wash cycle makes the subtilisin work less well.

Development

Until the advent of biotechnology, subtilisin's cleaning prowess was muted because of the very nature of how laundry detergent worked. Scientists used techniques of genetic engineering to improve the enzyme. In genetic engineering, select regions of

The Power of Enzymes

The catalyzing action of enzymes reduces the energy needed to accomplish a chemical reaction. In laundry detergent, this translates to less energy needed to clean clothes. As cold-water detergents are refined, the energy savings will be greater.

A study commissioned in Denmark showed that the reduction in wash temperatures from 140 degrees to 104 degrees Fahrenheit (60 degrees to 40 degrees Celcius) by five million residents would save the equivalent of 44,092 tons (40,000 metric tonnes) of coal annually. The energy needed to produce the enzyme (another bacterial protein) would only amount to about 331 tons (300 metric tonnes) of coal each year.

genetic material called genes can altered or replaced by other sequences. Genes contain a recipe, or code, for the production of proteins. Thus, changing the genetic structure allows the region of the gene encoding the critical methionine to be replaced. This strategy is called protein engineering.

Various replacements were unsuccessful, as they destroyed the enzymatic ability of the engineered subtilisin. However, some engineered subtilisin was more resistant to oxidation and still retained the wide spectrum of protein degradation (and thus removal of stains). The incorporation of the engineered subilisin in laundry detergent makes it possible to use bleach in the wash and still remove protein stains from the clothing.

Current Issues

Today, researchers are exploring the use of encapsulated enzymes in laundry detergents. In this approach, enzymes are enclosed in a lipid-based capsule. (Lipids are molecules of fats or oils.) This packaging helps make the enzyme less susceptible to other components of the detergent that could adversely affect the enzyme’s structure, as well as making it easier to dissolve the enzyme in the load of laundry.

Research also continues to engineer subtilisin in a way that increases its stain-removing capability. Additionally, researchers are exploring the use of other enzymes that are resistant to both hot and cold temperatures to increase the efficiency of cleaning. The use of enzymes that function efficiently in cold water is particularly interesting, because this would decrease the energy needed to wash clothing, as the water would not need to be warm to adequately remove stains. As of 2006, several cold water laundry detergent formulations are sold, but the technology is in its infancy.

Words to Know

Catalyst:	Any agent that accelerates a chemical reaction without entering the reaction or being changed by it.
Enzymes:	Proteins that help control the rate or speed of chemical reactions in the cell.

The use of an enzyme that has been improved for a specific purpose by means of protein engineering highlights a current issue of biotechnology—the use of the technology to enhance everyday life. Laundry detergent is an example of how biotechnology can be fruitfully applied to a problem in a way that is widely accepted. Other aspects of biotechnology that have claimed benefits to society, such as genetically modified foods, have been less well received.

■ ■ ■

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[*See Also* **Vol. 2, Recombinant DNA technology; Vol. 3, Enzymes, Industrial.**]

Molecular Farming

Description

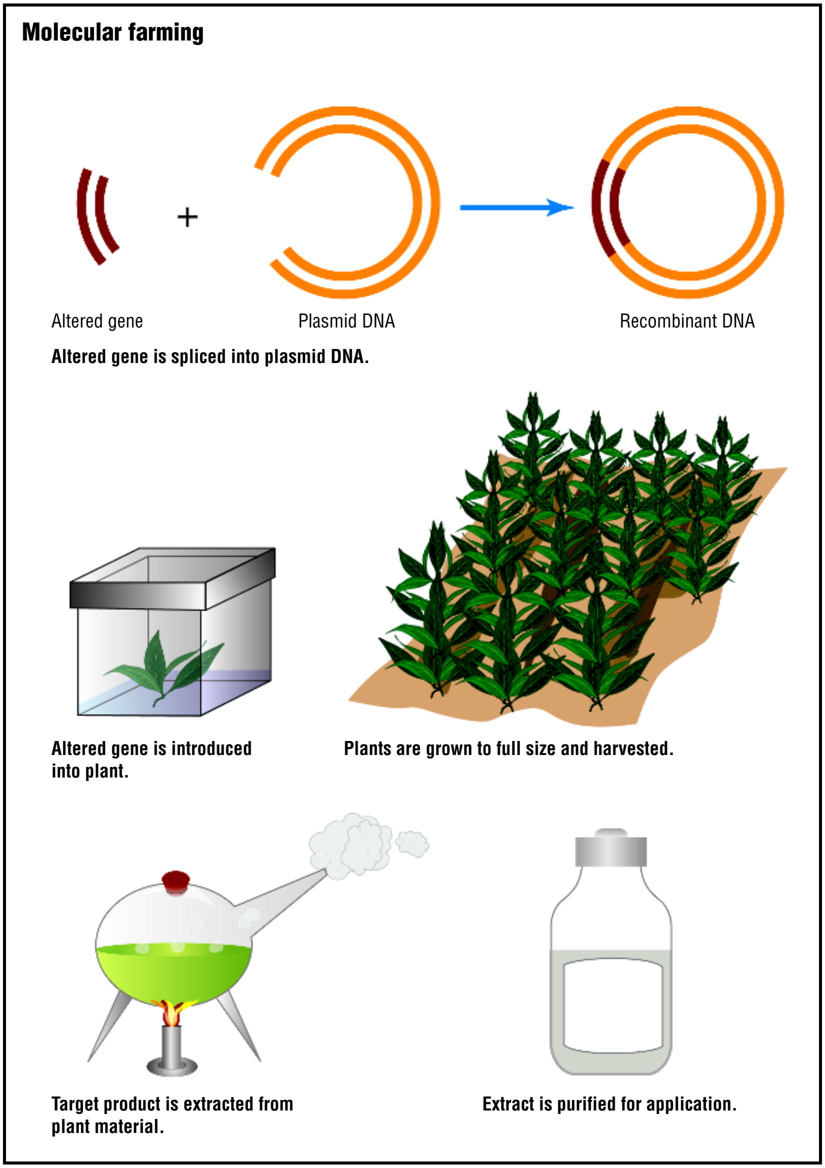
The production of corn that can fight cancer, or tobacco that can prevent HIV (human immunodeficiency virus, the virus that causes AIDS) are just two of the uses of molecular farming, a technology that combines the fields of biotechnology and agriculture.

The word “farming” typically means growing plants for food. But molecular farming (or “pharming,” as it is sometimes called) is the practice of modifying plant genes so that they produce proteins that can be used as medicines or vaccines. These proteins are known as plant-made pharmaceuticals (PMPs). Molecular farming can enable drug companies to produce medicines on a larger scale and at a lower cost than has been possible in the past.

The term pharming is also sometimes used to apply to the practice of genetically modifying animals so that they produce human proteins in their milk. (Proteins are the substances that living cells use to control their functions.) Sheep, goats, rabbits, and mice have all been studied for their ability to produce human proteins. These proteins can be used to as medicine to help people who are deficient in a certain type of protein.

Scientific Foundations

Plants do not naturally produce medicines and vaccines. Scientists must genetically modify them to have these traits. All plants (as well as animals and humans) contain DNA—the double-stranded chain of genetic information held in the nucleus of each cell. Segments of the DNA called genes give the instructions for the production of certain proteins.


Molecular farming
Altered gene
+
Plasmid DNA
Recombinant DNA
Altered gene is spliced into plasmid DNA.
Altered gene is introduced into plant.
Plants are grown to full size and harvested.
Target product is extracted from plant material.
Extract is purified for application.

How molecular farming works. First a targeted gene is altered and inserted in plasmid DNA, the structures that carry genetic information in bacteria. Once the bacteria is incorporated into plants, the plants grow and produce the desired substance. *Illustration by GGS Inc.*

By adding or changing genes in plant DNA, scientists can control the proteins that the plant produces. Genetically modifying a plant means taking a gene from another organism (often a human) and inserting it into the plant. Scientists have learned how to identify genes that code for certain proteins related to disease and protection from disease. They can remove the gene they want from human DNA and transfer it into the plant's cells. The transported gene is called a transgene. Plants that are produced as a result of this gene transfer are

Swine Vaccine in a Plate of Soybeans?

In 2002, the U.S. Department of Agriculture seized a silo of soybeans that contained a very small amount of corn that had been mixed in by mistake. Ordinarily, a little corn would not hurt anyone, so why all the fuss? The fuss occurred because this corn had been genetically modified with a swine vaccine. The soybeans involved in the mix-up (about 500,000 bushels, or 17,500 cubic meters) were destroyed, but the incident illustrated one of the big worries with molecular farming—the possibility that a genetically modified crop could get into the food supply and potentially make people sick. Critics remain concerned about the safety of molecular farming, although the government and drug companies say it is safe and carefully regulated.

called transgenic or genetically modified. The proteins produced in genetically modified cells are known as recombinant proteins.

Development

Plants have always been a source of products, from medicine to dyes. But recently, scientists have been able to genetically modify plants to enable them to produce very specific types of proteins that can be used to prevent and treat illness.

Two California scientists, Herbert Boyer (1936–) and Stanley Cohen (1935–), developed the process of recombinant DNA technology in the early 1970s. This is the process that enables today's scientists to insert DNA from one organism into the genetic makeup of another organism. It makes molecular farming possible. In the early 1980s, scientists tested the first genetically modified crops.

Molecular farming can be used to produce vaccines, antibiotics, and recombinant human proteins. Recombinant human proteins are proteins that are normally produced in the human body, but which scientists have genetically engineered plants or animals to produce. An example of this is insulin, which the body uses to regulate blood sugar levels. People who have diabetes need to take insulin because their bodies do not make enough of it naturally. In the past, insulin was taken from human cadavers (dead human beings) or from animals, but it could easily be contaminated. Molecular farming is one way to make proteins such as insulin more safely and cost-effectively.

To produce a vaccine, antibiotic, or other medicine in a plant, scientists first need to find the gene that codes for that trait—for

Words to Know

Antibiotic: A compound produced by a microorganism that kills other microorganisms or retards their growth. Genes for antibiotic resistance are used as markers to indicate that successful gene transfer has occurred.

Cadaver: A dead body.

Diabetes: A disease in which the body cannot make or properly use the hormone, insulin.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Gene gun: A device that shoots tiny metal bullets coated with DNA fragments into cells in order to alter their DNA permanently.

Human immunodeficiency virus (HIV): The virus that causes AIDS (acquired human immunodeficiency syndrome); HIV stands for human immunodeficiency virus.

Insulin: A substance made by the body (or by genetically engineered bacteria) that the body needs to regulate the amount of sugar in the blood.

Pollinate: Movement of pollen from the male reproductive organ to the female reproductive organ, usually followed by fertilization.

Purify: To make something clean by getting rid of any impurities.

Recombinant DNA technology: A technique for cutting and splicing together DNA from different sources.

Recombinant proteins: Proteins that are produced when DNA from two different organisms is combined.

Transgenic: A genetically engineered animal or plant that contains genes from another species.

Vaccine: A product that produces immunity by inducing the body to form antibodies against a particular agent. Usually made from dead or weakened bacteria or viruses, vaccines cause an immune system response that makes the person immune to (safe from) a certain disease.

Vector: A vehicle used to deliver foreign genes into another organism's DNA. Viruses are the most commonly used vectors.

example, resistance to a certain disease. They transfer the gene to the plant either using a virus or bacteria as a vector (an agent that carries a new gene into cells), or a gene gun (a device that uses DNA-coated projectiles to inject genetic material into cells). The plant will then begin to express, or produce, the protein on its own. After the crop is harvested, the protein is removed. It is purified and processed into the final product.

Current Issues

Molecular farming could potentially enable companies to produce medicines and vaccines more cheaply on a larger scale, providing a greater supply to the people who need them. But before molecular farming can enter general use, there are a few obstacles companies need to overcome. Some people are worried that a genetically modified plant could accidentally finds its way into the food supply. Would it be possible, for example, for someone to get a dose of antibiotic by mistake by eating an ear of corn? Another concern is that a genetically modified plant might pollinate (transfer pollen from one plant to another in order to make new plants) wild plants growing nearby and pass on the new gene. Or, the recombinant protein might leak out into the soil and get into the water supply.

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[*See Also* **Vol. 2, Corn, Genetically Engineered; Vol. 2, Genetic Engineering; Vol. 1, Genetically Modified Foods; Vol. 3, Nutraceuticals; Vol. 3, Plant-Made Pharmaceuticals.**]

Mussel Adhesive Protein

Description

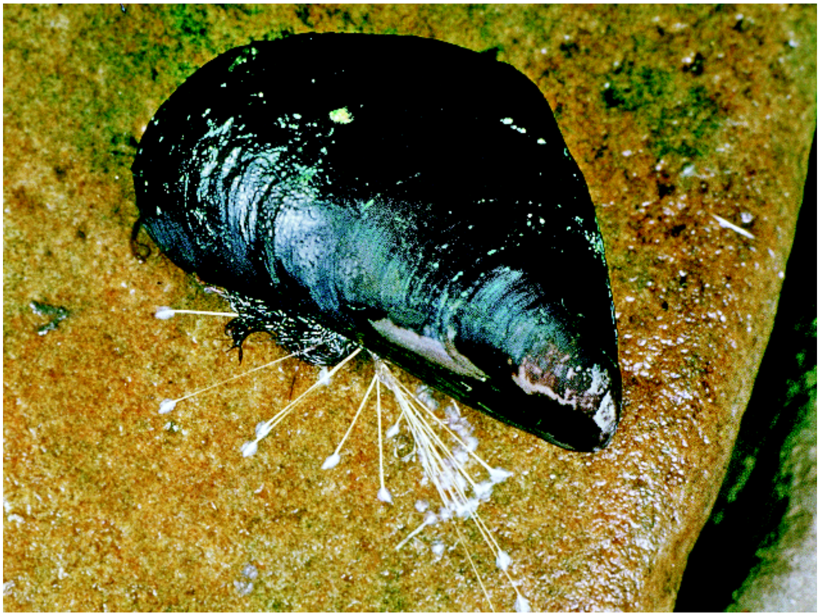
Mussel adhesive protein is a chemical formed by some varieties of mussel (animals related to oysters and clams). This protein anchors the mussel to underwater surfaces. (Proteins are substances that are the main components of living cells and control most of their functions.) The adhesive strength of the protein is one of the strongest known. This strength is retained even in water.

The protein is produced in the region of the mussel that contacts surfaces. The adhesive is excreted along with a catalyst (a substance that speeds up a chemical reaction without being changed by the reaction). The catalyst alters the character of the adhesive protein, changing it to a thread-like structure that stubbornly adheres to surfaces.

The protein-mediated adherence of muscles increases the drag on a ship's hull. Zebra mussels that now infest the North American Great Lakes cause water inlet and outlet pipes to become clogged. Despite these negative consequences, mussel adhesive protein is potentially useful for human purposes, especially in medical applications. These uses are being explored using biotechnological approaches.

Scientific Foundations

The common mussel (*Mytilus edulis*) is a shelled animal that has a region called the foot that slightly protrudes from the shell, and which is the anchoring portion. It can anchor itself to surfaces as varied as rocks and the hull of a ship. This is possible because of the adhesive protein secreted from cells that line the foot region. The protein is secreted as tiny threads that are called byssus. Another protein produced by the mussel causes the formation of



Mussel on a rock. The sticky threads coming from the mussel are its byssus. *Biophoto Associates/Photo Researchers, Inc.*

bonds between the threads, generating a gel-like collection of tentacles that are very adhesive.

The tremendous adhesive capability of the mussel protein has made it desirable for a variety of uses. A disadvantage is that the protein is only naturally available in large quantities if it can be harvested from huge numbers of mussels. An alternative to harvesting the naturally made protein is to produce it with genetic engineering technologies.

Development

One way to produce more of the adhesive protein is with recombinant DNA technology. DNA is the molecule of genetic information contained in nearly every living cell. Sections of DNA are called genes, and each gene contains a recipe, or code, for the production of a specific protein. Thus the production of mussel adhesive protein is contained in one of its genes. That gene can be isolated from the rest the animal's DNA and then inserted into another organism's DNA set, in this case the bacterium *Escherichia coli*. The new DNA set is called recombinant DNA. When the recombinant bacteria replicate, the transferred gene is replicated too, and it can subsequently be extracted from the bacteria's DNA and used commercially. This method, which is also used to produce human insulin, can manufacture the adhesive protein in large amounts.

Mussel Adhesive Protein and the Golden Fleece

Mussel adhesive protein has been known and used for centuries. Because of the protein's thread-like nature, weavers in ancient times used the material to create the finer thread used to make cloth. The cloth that was produced was very resilient and long-lasting. This aspect of the adhesive protein may even be the stuff of legend. In the story of Jason and the Argonauts, the Golden Fleece was the object of Jason's quest. Some historians believe that the garment was woven from the threads of the mussel protein, which would account for the garment's legendary durability.

An alternative to replicating the natural protein in bacteria is to make an artificial protein that mimics the adhesive power of the real thing. This involves reproducing the protein in a laboratory. Like all proteins, mussel adhesive protein is composed of a linear arrangement of chemical building blocks called amino acids. When the amino acids link together, their chemistry drives the formation of the proteins' three-dimensional structure. Chemical analysis has shown that the adhesive protein contains a high proportion of an amino acid called dihydroxyphenylalanine (DOPA).

To reproduce the protein, researchers have chemically bonded DOPA to a polymer (a chemical composed of many repeats of the same structural units). Research using the DOPA-polymer derivative has demonstrated strong adhesive capability. Furthermore, by attaching the derivative to various surfaces, adhesion to other kinds of surfaces can occur. For example, the protein can be attached to gold and titanium surfaces, which are commonly used medical implant materials.

Current Issues

The successful development of synthetic (artificially created) adhesive proteins that imitate the mussel version has opened the way for the use of the adhesive in, as two examples, medicine and in nanotechnology applications (which build devices on a molecular level). Sealing of junctions in the body with the adhesive, or the use of the adhesive to hold implanted devices in place, would be better than using staples or other hardware. At the near-atomic dimensions of the nanoscale level, the use of an adhesive would be much preferred over the use of hardware that would have to be engineered to retain its strength and that could be difficult to manipulate physically.

Words to Know

Adhesive: A substance that causes a physical attraction between different types of molecules.

Amino acids: Organic compounds whose molecules are one of the building blocks of a protein.

***Escherichia coli*:** *E. coli*, a species of bacteria that lives in the intestinal tract and that are often associated with fecal contamination.

Fouling: A term to describe the buildup of organisms (plants, algae, small animals, etc.) on a ship's hull, slowing its speed.

Polymer: A chemical compound formed by the combination of many smaller units.

Another current issue is to refine the surface-binding capability of the recombinant and synthetic versions of the adhesive protein, so that binding to surfaces other than gold and titanium occurs reliably. These surfaces include stainless steel and plastic. Given that the natural mussel protein is adept at binding to the hulls of ships, binding to steel medical implant surfaces should be possible.

Before the adhesive protein can be used medically, it will be necessary to ensure that the protein is not toxic. Animal and human testing will be necessary.

Finally, the potential of mussel adhesive protein as a tooth coating to retard the formation of dental plaque, and as an antifouling barrier on ship's hulls is being investigated.

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[*See Also* **Vol. 1, Insulin, Recombinant Human.**]

Nanotechnology, Molecular

Description

Molecular nanotechnology (MNT)—also called molecular manufacturing in its advanced stages—is the engineering of machines and devices at the atomic and molecular levels. MNT involves such fields as biology, chemistry, computer science, molecular physics, electrical engineering, mechanical engineering, and systems engineering. The pioneering ideas of American physicist Richard Feynman (1918–1988) formed the foundation of MNT. Feynman talked about the use of tiny factories to make nanomachines no larger than atoms to build advanced products.

The three main areas in the world for MNT development are the United States, Europe, and Japan. China, India, Israel, Taiwan, Singapore, and South Korea are also developing MNT. In the United States, some of the organizations financing nanotechnology research include the U.S. Department of Commerce, U.S. Department of Energy, National Aeronautics and Space Administration (NASA), National Institutes of Health, National Science Foundation, and the U.S. Department of Defense.

Scientific Foundations

MNT uses various technologies so that the structure of matter is controlled at the level of molecules, or even down to small numbers of atoms. Atoms come together to form molecules. This molecular level is called nanometer-scale, or a level from 0.1 to 100 nanometers. One hydrogen atom, for instance, has a diameter of about 0.1 nanometer. One molecule, when composed of about thirty atoms, has a diameter of only about one nanometer. In everyday life, about 50,000 nanometers make up the width of one human hair. Materials used in MNT are called nanocrystals or nanomaterials. Nanotechnology is important for future scientific development because many of the biological and physical processes in the world operate at this level. In fact, a solid cannot be made smaller than the nanoscale level.

Development

In 1959, Richard Feynman described the building of machines with the use of individual atoms. In the 1970s, Japanese materials engineer Norio Taniguchi used the term nanotechnology in a scientific paper and American engineer Kim Eric Drexler (1955–) used molecular nanotechnology concepts at the Massachusetts Institute of Technology. In 1981, the invention of scanning tunneling microscopes allowed scientists to control individual atoms. Drexler wrote the first book on MNT in 1986: *Engines of Creation: The Coming Era of Nanotechnology*. The first protein (a substance produced by living cells) was engineered with MNT in 1987 and Japan began to fund nanotechnology projects in 1990. Carbon nanotubes were first created in 1991. Also called buckytubes, they are cylindrical carbon molecules with properties that are important to the development of MNT.

The U.S. government began to study nanotechnology in 1993. Around this time, Zyvex, the first company to develop MNT, was established in Texas. In 1998, scientists at New York University created the first DNA-based nanomechanical device. (DNA, deoxyribonucleic acid, is the double-stranded chain of genetic information held in the nucleus of each cell.) U.S. President William Clinton (1946–) announced the National Nanotechnology Initiative in 2000, which increased nanotechnology research and development. In 2003, the United States announced the first military center for MNT applications. One year later, the first civilian center for nanomechanical systems was established at the University of California at Berkeley.

Current Issues

Molecular nanotechnology is still in the very early stages of research and development. Only simple materials can be produced because scientists can only control the structure of matter with small resources. Sometime in the future, MNT is predicted to produce complex materials and devices with very unique and valuable properties. Today, a committee of international experts is studying the impact of developing nanosystems.

Gray Goo

Kim Eric Drexler, a pioneer of molecular nanotechnology, went to school at Massachusetts Institute of Technology in the 1970s. Late in that decade, Drexler advanced theories about molecular nanotechnology, primarily after hearing about the technology from a talk given by Richard Feynman called *There's Plenty of Room at the Bottom*. In 1986, Drexler published his book *Engines of Creation: The Coming Era of Nanotechnology*. Within the book, Drexler described what might happen if a material made with molecular nanotechnology went out of control. In this futuristic disaster, molecular robotic mutants eat all living matter on Earth as they produce more and more of themselves. Drexler called the dangerous molecular robots ‘‘gray goo.’’

Environmental groups have already voiced health and environmental issues from future MNT applications. In addition, some members of the scientific community doubt the ability of humans to build machines at the atomic level. Some scientists are worried that MNT could produce risks to society in general. For instance, MNT products in the defense industry could make weapons much less expensive to build and much more destructive when used.

Scientists theorize that MNT products could duplicate themselves in such great numbers that some naturally occurring organisms could be destroyed. However, experts state that MNT would only be developed under very controlled circumstances. Regulatory and standards agencies are discussing such issues.

The quality and cost of making products depends on the particular arrangement of atoms and molecules. If scientists and engineers can better control these particles, less energy would be needed for manufacturing, and less pollution would be produced.

The general goals of MNT are to develop clean energy solutions; provide clean air and water worldwide; improve the health and life span of humans; increase agricultural productivity; make materials many times stronger than steel but very lightweight; make technology available throughout the world by storing large amounts of information in tiny volumes; and develop better ways to explore space. Medical scientists predict that tiny machines will eventually travel inside the human body to clean arteries, destroy cancer cells, and repair tissue and organs. Aerospace scientists believe tiny machines will reduce the costs and dangers

Words to Know

Deoxyribonucleic acid (DNA): The double-helix shaped molecule that serves as the carrier of genetic information for humans and most organisms.

Nanometer: The distance equal to one-billionth of a meter.

Organism: Any living thing.

Scanning tunneling microscope: A device that emits a focused beam of electrons to scan the surface of a sample. Secondary electrons released from the sample are used to produce a signal that can in turn produce an image.

of exploring space. Computer scientists state that MNT-based computers would be millions of times faster than current computers.

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[*See Also* **Vol. 1, Bioethics; Vol. 3, Biological Weapons; Vol. 3, Biorobotics.**]

Nutraceuticals

Description

A broad definition of nutraceutical (NOO-trah-soo-ti-cal) is any food that shows health or medical benefits beyond traditional nutritional value. Such foods include dietary supplements, functional foods, and medicinal foods. All foods within these three groups are called nutraceuticals.

However, the term nutraceutical is defined differently depending on the source. Scientists define nutraceutical in one way, while food manufacturers define it another way. Some individuals and groups use nutraceutical as an overall name for any fortified food, while others use it only to refer to dietary supplements. Although a legal definition for nutraceutical does not exist, most people in the industry consider nutraceuticals to be any food advertised as having specific health benefits. Nutraceuticals also have been called designer foods, pharmafoods, and phytochemicals.

A spread that provides beneficial chemicals, called omega-3 fatty acids, from fish oils is one example of a nutraceutical. If eaten in large enough quantities, omega-3 fatty acids can lower a type of fat in the blood called triglycerides. This reduction lowers the risk of heart attacks by lowering cholesterol (a lipid or fat that is made by the liver) levels. Benecol® is one specific product that contains omega-3 fatty acids and claims to help reduce the risk of heart attacks. It contains stanol esters, an ingredient derived from plants like corn, rye, and wheat. Advertisements for Benecol® state that one tablespoon (one serving) of Benecol® spread contains 0.03 ounce (0.85 gram) of stanol esters and that two to three servings each day, eaten instead of regular margarine spreads, can lower cholesterol levels.

St. John's wort plant, which is taken as a dietary supplement to treat mild depression. © *Roy Morsch/ Corbis.*

Currently, the term nutraceutical is used only in the marketing of foods. According to the *Nutrition Business Journal*, in 2005 the nutraceutical industry in the United States generated about $68.6 billion in sales. Nutraceuticals are especially popular in the United States, Japan, Canada, and Europe. According to a 2003 report from *Nutraceuticals Japan*, the industry in Japan generated $21.1 billion, second only to the United States.

Scientific Foundations

The three main groups of nutraceuticals are: dietary supplements, functional foods, and medicinal foods. Dietary supplements are ingredients intended to supplement the diet. They include vitamins, minerals, and botanicals (plant-based supplements) such as ginseng, ginkgo biloba, and St. John's wort. Functional foods are products made with naturally occurring ingredients specifically to improve health or performance. Such foods include oats, bran, canola oil, stanols (such as Benecol®), enriched cereals and breads, sports drinks, teas, and vitamin-enriched snack foods. Medicinal foods are those for the treatment or prevention of diseases. They include foods from genetically altered animals and plants, proteins (such as lactoferrin, which is iron-enriched), and health bars with added medications.

Some specific consumer nutraceuticals that are advertised as having health benefits due to added ingredients include Dannon's Activia® (a bio-yogurt that contains substances promoting the growth of healthy bacteria), Kellogg's All-Bran Plus® (a calcium-fortified breakfast cereal that also contains vitamins C and E), Tropicana Calcium-Fortified Orange Juice®, and Kellogg's Nutri-Grain® bars (calcium-fortified energy bars).

Development

Nutraceutical originates from the words *nutr*ition and pharm*aceutical*. American clinical pharmacologist Stephen DeFelice invented the word in 1989. At that time, DeFelice defined nutraceutical as "a food (or part of a food) that provides medical or health benefits, including the prevention and/or treatment of a disease." This definition includes such foods as dietary supplements, fatless meat, fat substitutes, fiber-enriched foods, low-calorie prepared foods, skim milk, sugar substitutes, and fruits and vegetables.

The word nutraceutical was invented to define natural, nontoxic supplements designed to improve health through nutrition. Nutraceuticals are different from other supplements because their health benefits are supported with scientific research.

In October 1994, the U.S. Dietary Supplement Health and Education Act (DSHEA) was signed into law. The Act states that there is a relationship between eating certain nutrients and dietary supplements and the prevention of certain diseases such as cancer and heart disease. The Act provides the nutraceutical industry with guidelines to standardize nutraceuticals for higher quality and

The Blueberry: A Natural Nutraceutical

The blueberry is a fat- and salt-free fruit that is a source of fiber; vitamins A, C, and E; and antioxidants. Antioxidants are substances that slow or block oxidation, a process in which atoms or molecules lose electrons. They are beneficial to human health because they help control the damage caused by free radicals. Free radicals are byproducts of oxidation reactions that are known to cause cancer, cardiovascular disease, and memory loss. Scientific studies have shown that blueberries help lower cholesterol levels. Blueberries are a healthy food to eat—one that comes directly from nature and does not need to be made into a bar, cereal, or other processed food to be considered a nutraceutical.

consistency. The DSHEA also requires that claims made for nutraceuticals be truthful, not misleading, and based on scientific research with respect to a product's health benefits.

Current Issues

According to the American Association of Pharmaceutical Scientists (AAPS), the nutraceutical industry is currently facing a number of issues. Some of these issues include product availability, research validity, product stability, quality assurance, uniformity of content, and product safety. In the past, the industry has primarily regulated itself, but the U.S. government is slowly introducing external regulations. The types of advertising claims that the companies selling nutraceuticals can make are regulated by the DSHEA. For example, the statement "provides calcium for strong bones" is acceptable, while "provides calcium to prevent osteoporosis" is not acceptable under federal guidelines.

Nutraceuticals cause controversy because they combine the concepts of foods and medicines into one product. Consequently, the nutraceutical industry is seen as a possible competitor with the pharmaceutical industry. Its products are viewed increasingly as equal or better when compared to pharmaceutical (drug) products, and this may take profits away from pharmaceutical companies. In addition, pharmaceutical products are frequently seen as toxic by consumers, whereas nutraceuticals are advertised as non-toxic.

Nutraceuticals are generally more expensive than conventional foods. In many cases, it is possible to receive the same helpful ingredients by purchasing less expensive products and eating a

Words to Know

Antioxidant: A chemical compound that has the ability to prevent the oxidation of substances with which it is associated. Oxidation can damage cells.

Cholesterol: A common type of steroid in the body, which is made in the liver. High levels are associated with cardiovascular disease.

Free radical: An unstable particle that can cause damage in cells.

Oxidation: A biochemical process which is part of metabolism. It involves the steady but relatively slow release of energy from food molecules for cell activity.

Pharmacology: The science of the properties, uses, and effects of drugs.

Stanol ester: A group of chemical compounds that reduce the amount of low-density lipoprotein (LDL) cholesterol in blood.

Triglyceride: Natural fat in tissue, which comes from animal and plant fats and oils, that is considered dangerous to human health.

healthy, balanced diet. For example, a calcium-fortified fruit drink is more costly than a glass of milk, which naturally contains the mineral calcium. A stimulation drink (one that contains large amounts of caffeine and sugar) is about twice as expensive as the price of a can of cola.

Nevertheless, nutraceuticals appeal to consumers because they are convenient and imply healthier lifestyles than traditional foods. Some offer concentrated amounts of ingredients that can bring about health benefits quicker than through eating conventional healthy foods alone.

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[*See Also* **Vol. 2, Fat Substitutes; Vol. 1, Genetically Modified Foods.**]

Oil-Seed Crops

Description

Oil-seed crops are agricultural plants that are grown for the oil contained in their seeds. Peanuts, sunflowers, corn, olives, coconuts, and soybeans are some examples of these crops.

Oil-seed crops are classified as traditional and non-traditional. Canola (rapeseed), groundnuts, and castor beans are examples of traditional oil-seed crops, while non-traditional oil-seed crops include soybeans, sunflowers, corn, and palms. Peanuts, sunflowers, soybeans, cotton, and rapeseed are cultivated mainly for edible oils. Oils from other plants, such as castor beans, are extracted for industrial use.

The criteria that make an oil-yielding plant desirable vary according to changing tastes and scientific developments. Today, oils with high levels of nutrients and healthy fat are desirable. New varieties are being genetically engineered to modify the oil contained in these crops.

Scientific Foundations

Both the nutritional benefits and the industrial uses of oil-seed crops depend on the fatty acid composition of the oil that is extracted from the seeds. Fats are combinations of various fatty acids with unique physiological and metabolic characteristics. Saturated fats are solid at room temperature, whereas unsaturated fats (oils) are usually liquid at room temperature. Unsaturated fats are divided into two categories: monounsaturated fats and polyunsaturated fats. If these fats are used instead of saturated fats in diet, they help significantly lower the risk of heart disease.

A large field of canola, or rapeseed, in British Columbia. © *Gunter Marx/ Corbis.*

Canola, olive, peanut, and sunflower oils are rich in monounsaturated fats. For example, sunflower oil is high in oleic acid, a monounsaturated fat. Eating oleic acid has been shown to lower cholesterol and triglycerides levels in the body, making the oil a healthy dietary choice. Cholesterol and triglycerides are lipids (fats) that are found naturally in blood and body tissues. High levels of these lipids have been associated with heart disease. Also, high levels of oleic acid keep the oil from becoming rancid and eliminate the need for oil hydrogenation, a process that stabilizes oils.

Development

In ancient times, most foods were eaten in their natural form. Gradually, natural foods were replaced by processed foods and spices were added to enhance the flavor. Cooking time was increased to blend the flavor of spices with the basic ingredients. Bland, pale, chemically extracted oils replaced flavorful, nutrient-rich oils. However, processing often destroyed the essential vitamins and minerals that the foods contained naturally.

The Origins of the Sunflower

The sunflower was first discovered in South America, where its seeds were eaten by local residents. The seeds were also used for medicinal purposes, and its petals were used to make yellow color for face painting. Explorers brought sunflower seeds back to Europe, and the Spanish used these seeds to study the plant. By the end of the sixteenth century, sunflowers were quite common in Spain. Initially, sunflowers were grown as ornamental plants rather than for their oil. From Spain, the sunflower spread across several European countries, where its commercial uses were gradually developed.

In response to research studies, many consumers have begun to demand foods that are processed minimally, if at all. Countries are enacting regulations to encourage manufacturers to retain natural flavors and nutrients in their food products.

Both traditional plant breeding techniques and genetic engineering are used to create oil-seed crop varieties that produce higher yields and increased income for farmers. Genetically modified varieties have been created that eliminate some component of the original plant or that add a new component in order to improve the qualities of the oil or to make the crop easier to process.

Several organizations are exploring the development of oil-seed crop varieties as sources of renewable energy, some of which can successfully be substituted for petroleum and its products. For example, biodiesel fuel can be manufactured from a variety of vegetable oils. This type of fuel reduces the amount of harmful emissions produced by cars and other motor vehicles, and it is also biodegradable and non-toxic.

Certain wild plants, such as calendula, *Euphorbia lagascae*, and coriander, are being studied and cultivated for their rich oil content. Scientists are growing these plants on a small scale to determine their suitability for use in the oleochemical industry. Oleochemicals are chemicals derived from biological oils or fats.

Current Issues

Biotechnology companies and researchers continue to work on the development of nutritionally desirable oil-seed crops. Modifications are made to the fatty acid composition of oil seeds so that the oils produced are more nutritious or have a longer shelf life. For example, scientists are working to develop soybean varieties with lower levels of linolenic acid. Linolenic acid can make the oil turn rancid. Although soybeans naturally contain low levels of this

Words to Know

Crop: Agricultural plant grown on a farm.

Fatty acid: An acid made of carbon, hydrogen, and oxygen that is found in body fat.

Hydrogenation: A chemical reaction in which hydrogen is added to a compound.

Oleochemicals: Chemicals derived from vegetable oils.

Polyunsaturated fat: A fat missing two or more hydrogen atoms from the maximum number that can be bonded to carbon atoms of the compound. These fats can remain liquid at room temperatures.

Saturated fat: A fat containing the maximum number that can be bonded to carbon atoms of the compound.

Unsaturated fat: Fats found in vegetable oils including canola, peanut, olive, sunflower, safflower, soybean, corn, and cottonseed. Unsaturated fats are healthier than saturated fats.

acid, the engineering of varieties with even lower levels will produce oil that stays fresher longer.

Some oil-seed plants, such as rapeseed and sunflower, are being modified to suit the requirements of the oleochemical industry for high fatty acid content. In addition, work is underway to increase the nutritional content of the plant residue (known as meal) that is left after the oil is extracted. This meal is used as a livestock feed. Increasing its nutritional content will make it more valuable.

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[*See Also* **Vol. 2, Fat Substitutes.**]

Organic Acids, Commercial Use

Description

Organic compounds are made of carbon- and hydrogen-containing substances. Those that are acidic in nature are known as organic acids. Acids are strong substances with a low pH (a measure of acidity) and a sharp taste. Commonly used organic acids include amino acids, acetic acid, formic acid, ascorbic acid, citric acid, oxalic acid, lactic acid, salicylic acid, and propionic acid.

The commonly used organic acids have wide-ranging commercial uses. The antifungal property of propionic acid is used as a preservative to save baled hay from fungal growth. Hay treated with propionic acid can be stored for up to six months. Acetic acid is the key component of vinegar, giving it the characteristic taste and smell. Vinegar typically adds acidity to pickles, salad dressings, and several other foods. Other uses of acetic acid are in the manufacture of photographic films, synthetic fabrics, cleaning products, soft drinks, adhesives, inks, mordants used as binders in dyeing fabric, and medicines.

Plants that bear vegetables and fruits also contain organic acids. A well-known example is citrus fruit, which derive its name from citric acid. Lemons, oranges, pomegranates, tangerines, limes, strawberries, cranberries, apples, and several other fruits are rich sources of citric acid. Tartaric acid, another organic acid, is abundantly found in unripe grapes and mangos. Ripening converts the sour tartaric acid into sugars, which makes the fruits sweet in taste.

Scientific Foundations

Organic acids are produced as part of the metabolic processes in living organisms. Though they may be produced in small quantities, organic acids are vital for human survival. Amino acids are an

What Is Organic Chemistry?

Organic chemistry is the field of studying organic chemical compounds, several of which are important for the survival of living systems. The study of biologically important organic compounds—including proteins, enzymes (biological agents that speed up chemical reactions), hormones (chemical messengers in the body), fats, vitamins, carbohydrates, and amino acids—is referred to as biochemistry.

instance of organic acids that are of prime importance to all living beings. Amino acids are the building blocks of proteins, substances that in turn create cells and their components.

Organic acids consist of organic compounds made from various forms of carbon and hydrogen, along with groups of atoms of oxygen and hydrogen. These are acidic groups, hence the name organic acids.

Organic acids can be used to convert inexpensive materials into compounds of great industrial value. Consequently, all industries use organic acids in some form.

Development

Organic acids are so widespread in nature that their effects have been noticed since ancient times. Although people did not understand the science behind organic acids, many of these acids have been used for centuries. For instance, due to the corrosive (chemically destructive) nature of acetic acid, it was used to prepare colors from metals such as copper and lead. One of the oldest uses of acetic acid is in the creation of vinegar.

By the late nineteenth century, scientists observed that *Acetobacter* (bacteria that produce acetic acid) are found in water, soil, and crops indicating the widespread occurrence of acetic acid in nature. It was eventually discovered that if additional oxygen could be provided to *Acetobacter*, vinegar production could be accelerated. In 1949, chemists Heinrich Ebner and Otto Hromatka used this principle to introduce methods for quicker mass production of vinegar. Such methods are still used.

Among other organic acids, acetyl salicylic acid has been used by people for ages. The ancient Greeks were familiar with the fever-reducing effects of willow bark (an herb derived from trees). Much later, in 1827, the fever- and pain-reducing element of willow bark was identified as salicin (a compound containing glucose and some other substances). After several experiments, in

Organic Compounds

The term ''organic'' refers to any substance derived from a living organism. Organic compounds are so called because until the nineteenth century, people thought only living organisms could produce them. Though the term is still in use, organic acids are produced commercially as well.

1853, French chemist Charles Gerhardt (1816–1856) synthetically produced acetyl salicylic acid. In 1893, German chemist Felix Hoffman converted acetyl salicylic acid into aspirin by reducing its acidity and giving it an appealing taste. Aspirin is one of the most common drugs used for fever and pain.

Current Issues

In recent times, organic acids are being used for detecting diseases. An organic acid test, usually done on a urine sample, indicates the metabolic health of an organism. Unusual concentrations of organic acids may point to a genetic disorder, nutrient deficiency, or excessive amounts of other substances. Based on the analysis, doctors can prescribe relevant medication. Seemingly healthy individuals also gain important insight from organic acid tests.

All types of animal feed, even under the most suitable conditions, contain microorganisms, tiny organisms like bacteria, viruses, and yeast. With time, the quantity of microorganisms increase to such an extent that it makes the feed unpalatable, resulting in reduced consumption. Microorganisms in feed can cause disease in animals. Formic acid has been found to inhibit the growth of yeast and bacteria. Propionic acid restricts fungal development. Together, these two organic acids are used extensively in animal feed to prevent its contamination and save animals from germs.

Salicylic acid is produced in plants as a means of protection against infections. Plants with a higher concentration of salicylic acid are thought to be better at resisting the effects of disease-causing germs. Scientists are experimenting with developing plant varieties that produce higher quantities of salicylic acid, which would enhance their resistance to diseases.

Formic acid found in ants and plants is now available commercially in its pure form. It is extensively used in the pharmaceutical, textile, and leather industries. It is also used for preservation of livestock feed.

Words to Know

Acidic: Having the qualities of an acid, one of which is that it will react with and neutralize metallic oxides.

Amino acids: Organic compounds whose molecules are one of the building blocks of a protein.

Metabolic: Related to the chemical processes of an organ or organism.

In certain types of soils, presence of aluminum is detrimental to plant growth. Some plants thriving in such soils have been observed to release large amounts of organic acids, which in turn bind with (chemically attach to) aluminum present in the soil to form molecules that are unable to enter plant roots. Producing higher amounts of organic acids thus helps plants cope with otherwise poisonous soil. Scientists are using this principle to produce aluminum-tolerant varieties of plants that release organic acids in amounts higher than usual.

Repeated experiments and technological advancements in biotechnology have unraveled several mysteries of organic acids. Medical experts continue to research various commercial uses of organic acids.

■ ■ ■

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[*See Also* **Vol. 2, Agriculture; Vol. 3, Amino Acids, Commercial Use; Vol. 2, Disease-Resistant Crops.**]

Patents in Biotechnology

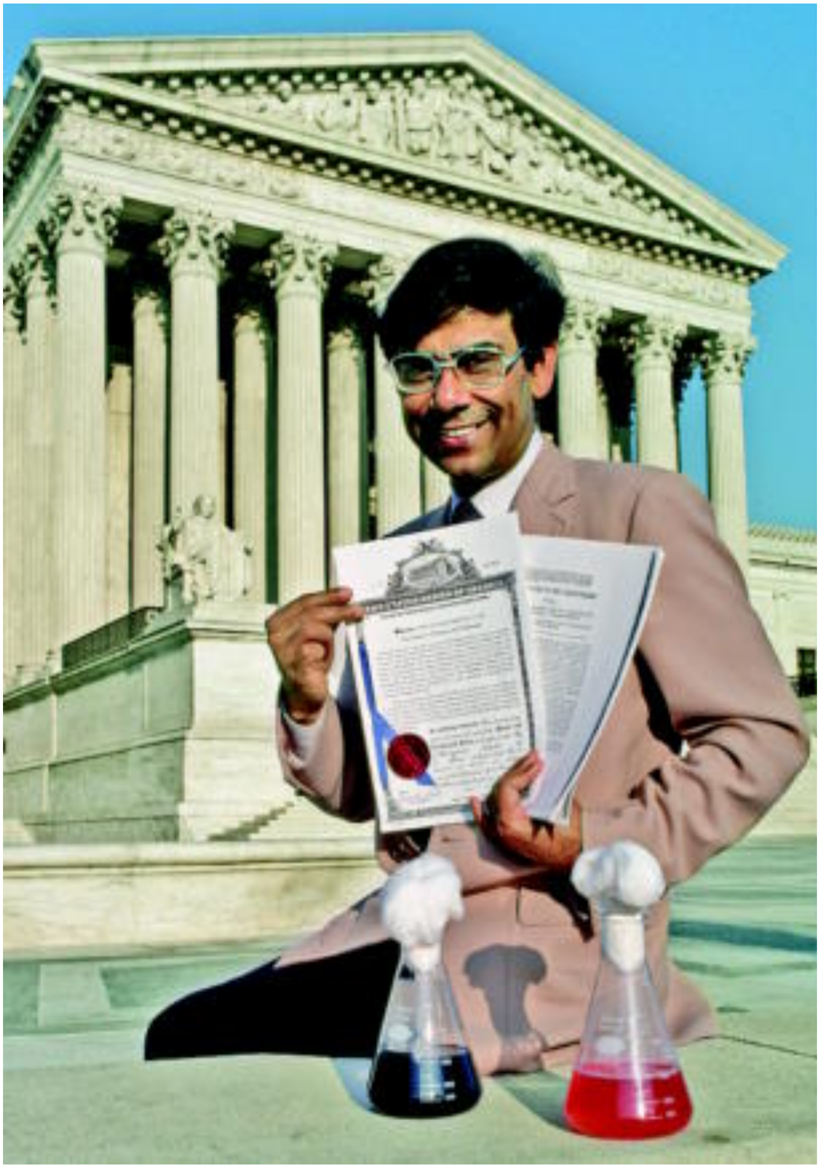
Description

New inventions are created every day, and this is especially true in the field of biotechnology. Biotechnology companies are constantly inventing new treatments for disease, but they need incentives to keep doing so. They want to make money from their inventions. If other companies were allowed to simply copy their products or processes, they would not be able to stay in business. That is why getting patents is so important to the existence of the industry.

Scientific Foundations

A patent is a document issued by a government agency that describes and protects an invention. In the United States, companies or inventors submit patent applications for new products or processes to the U.S. Patent and Trademark Office (PTO). The application describes the invention, sometimes shows drawings of it, and sets out claims defining the rights the inventor thinks he or she is entitled to receive. An examiner at the PTO reviews each application to make sure the product or process is truly new and has not been described before. If a patent is granted, it gives the patent owner the legal right to stop anyone else from making or selling the same product. That right lasts for a period of twenty years from the date that the patent application was first filed.

Biotechnology patents often have to do with manipulated deoxyribonucleic acid (DNA). This is the double-stranded molecule of genetic information contained in nearly every cell. A gene is a segment of DNA that instructs the body to produce a specific protein. (Proteins are substances that control most cell functions.) Scientists can take genes from one animal or plant and insert them into another animal or plant



Dr. Anada Chakrabarty, the first scientist to receive a patent on a living thing from the U.S. Patent Office, in front of the U.S. Supreme Court. His patent was for his creation of bacteria that were genetically modified to clean up oil spills. © *Ted Spiegel/ Corbis.*

to make it produce proteins it would not make naturally. This process of manipulating DNA is called genetic engineering, and the animal or plant that receives the new genes is said to be transgenic.

Development

The basis of today's patent system has existed since soon after the American Revolutionary War (1775–83). In the first article of the U.S. Constitution, the founding fathers wrote: "Congress shall

Should Nature Be Patented?

Many inventions throughout the years have obviously deserved patents, such as Eli Whitney's cotton gin and Alexander Graham Bell's telephone. Others have been less obvious and more controversial. In 1980, a scientist named Ananda Chakrabarty applied for a patent for a new strain of bacteria. The bacteria had been genetically engineered to clean up oil slicks. The U.S. Supreme Court concluded that Chakrabarty deserved the patent. Although the bacteria occurred in nature, the Court said they had been altered by scientists to have characteristics that they would not have had naturally. There is still some debate over whether naturally occurring organisms can be patented. But companies continue to receive patents for human genes that are used to make medicines and tests for diseases.

have the power to promote the progress of science and useful arts, by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries."

The first U.S. patent was granted in 1790 to Samuel Hopkins for a new method of making potash, a chemical used to produce soap, glass, and fertilizer. The official PTO was established in 1836. At that time, patents were issued for a period of fourteen years. That period was later increased to seventeen years. Patents now provide protection for twenty years from the first filing date.

Many biotechnology products and processes have been patented over the years, including industrial proteins such as enzymes (proteins that trigger chemical reactions), medicines, disease-resistant plants, tests for diseases, yeast culture, and methods for making beer. Companies also have patented DNA sequences and transgenic animals and plants.

To be patented, the invention in question must be new, useful, and not already known to the public. For example, if scientists discover a new gene in the human body, they cannot patent it in its natural state. They can patent a gene, however, if they are the first to isolate it and identify a use for it, such as producing a protein medicine. One example of this is interferon, a protein that helps regulate the immune system and helps stop viruses (tiny organisms that can cause disease). Interferon has been patented for preventing and treating diseases such as leukemia (a cancer that affects the blood-forming cells in bone marrow) and hepatitis C (a disease of the liver).

DNA and genes also can be patented if they are inserted into an animal or plant to cause it to produce a new protein that can be used to treat disease. Companies can not only patent the transgenic

Words to Know

Deoxyribonucleic acid (DNA):	The double-helix shaped molecule that serves as the carrier of genetic information for humans and most organisms.
Enzyme:	A protein that helps control the rate or speed of chemical reactions in the cell.
Gene:	A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.
Genetic engineering:	The manipulation of genetic material to produce specific results in an organism.
Hepatitis:	General inflammation of the liver; may be caused by viral infection or by excessive alcohol consumption.
Interferon:	A chemical messenger (cytokine) that plays a role in immune response. Also used as a drug.
Leukemia:	A cancer of the blood-producing cells in bone marrow.
Patent:	A grant given by a governmental body that allows a person or company sole rights to make, use or sell a new invention.
Transgenic:	A genetically engineered animal or plant that contains genes from another species.
Virus:	A very simple microorganism, much smaller than bacteria, that enters and multiples within cells. Viruses often exchange or transfer their genetic material (DNA or RNA) to cells and can cause diseases such as chickenpox, hepatitis, measles, and mumps.
Yeast:	A microorganism of the fungus family that promotes alcoholic fermentation, and is also used as a leavening (an agent that makes dough rise) in baking.

animals and plants themselves, but they can also patent the gene sequence that was inserted, and the protein that is produced as a result of this genetic engineering.

Current Issues

Biotechnology companies say they depend on patents to protect their inventions. But opponents of biotechnology patents argue that companies should not have the right to patent genes because they exist in nature. They also say that some biotechnology patents get in the way of innovation by preventing other companies from researching new treatments that could potentially save lives. For example, scientists at a biotechnology company might be working on a new treatment for a disease that is caused by several genes. If those genes have already been patented, the biotechnology company would have to pay license fees to the patent owner before being able to conduct its research.

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[*See Also* **Vol. 3, Enzymes, Industrial; Vol. 2, Genetic Engineering; Vol. 2, Genetically Engineered Animals; Vol. 3, Plant-Made Pharmaceuticals; Vol. 2, Transgenic Animals; Vol. 2, Transgenic Plants.**]

Plant-Made Pharmaceuticals

Description

A pharmaceutical is a drug, medicine, or vaccine. Plant-made pharmaceuticals are made from plants that are genetically engineered to produce pharmaceuticals, a process also known as biopharming, or just pharming. A genetically engineered plant is any plant whose DNA (deoxyribonucleic acid, its genetic information) has been changed in the laboratory.

As of 2006, no biopharmed drugs were being sold yet, but many were being researched by scientists. Genetically engineered varieties of corn, rice, potatoes, alfalfa, safflower, flax, tobacco, and bananas had all been engineered that could make drugs in their tissues.

Making a drug is usually a complicated chemical process. Expensive machines and skilled chemists are needed. However, living things are good at chemistry. Every living cell carries out thousands of complicated chemical reactions every day. What's more, life makes more life: corn plants can make more corn plants by the millions or billions. If the DNA of a plant can be changed so that its cells make a medicine, and if that medicine can be extracted from the crop or even eaten as part of the plant, it might be a much cheaper way to make that medicine. Making medicine more cheaply is the goal of biopharming.

Animals, yeast, and bacteria can also be genetically engineered to produce pharmaceuticals. Sometimes the word "biopharming" (the word comes from "bio" for life and "pharm" for pharmaceutical) is also used to refer to the use of animals to make pharmaceuticals. Cows, sheep, and goats have all been genetically engineered to make pharmaceuticals in their milk. The animals used in biopharming are not the same animals that are used to make food for people; they can be found only in special farms.

Scientist with an experimental plant that makes an HIV/AIDS vaccine. *David Parker/Photo Researchers, Inc.*

Scientific Foundations

Most cells, whether they are single-celled organisms like bacteria or part of a many-celled plant or animal, contain all the DNA that the organism needs to make offspring. DNA also tells each cell exactly how to make all the thousands of protein molecules (clusters of atoms) that it needs throughout its life. In nature, small changes in DNA occur over time. This is evolution, the process that has produced all Earth's living things, including people. Genetic engineering, unlike evolution, can make major changes in DNA overnight. This is usually done by shooting thousands of copies of a gene (a short section of DNA that does a particular job) into a cell with a special kind of shotgun. The gene is taken up by the cell and added to its DNA.

A biopharmed plant is made by adding a gene that tells the cells of the plant how to make a drug, medicine, or vaccine. The plant does not need the pharmaceutical, but makes it anyway.

Biopharmed Rice

In 2006, the U.S. company Ventria Bioscience was testing an anti-diarrhea drug made by biopharmed rice. The rice could be ground into a powder and eaten by children with diarrhea. In poor countries, diarrhea kills 1.5 million young children every year. However, Ventria's biopharmed product has been the center of a firestorm of protest. Japanese rice buyers, worried that food rice might be contaminated by anti-diarrhea rice, said in 2004 that they would not buy rice from California if Ventria was allowed to grow its rice there. Ventria was forced to give up the idea of growing its rice in California—not by environmentalists or anti-genetic engineering activists, but by the rice industry. Ventria has managed to carry on its research elsewhere, but its troubles are typical of those suffered by the biopharming industry.

Development

Before scientists could make useful changes in DNA, they needed to understand how the DNA molecule was put together. In 1953, American biologist James Watson (1928–) and English biologist Francis Crick (1916–2004) were the first to discover that DNA is shaped like a twisted ladder. They also found that information is stored along the DNA molecule in a chemical code. In 1970, restriction enzymes were discovered. These chemicals made it possible to do genetic engineering because they allow biologists to cut DNA molecules at chosen points. In 1986, genetically engineered tobacco was the first genetically engineered crop to be tested in open fields. Genetically engineered varieties of tomatoes, corn, cotton, and other crops were grown and sold starting in the 1990s. Today, most packaged foods in a typical American supermarket contain some material from genetically engineered plants.

One of the first uses of genetic engineering was the making of pharmaceuticals. In 1982, insulin made from genetically engineered bacteria was approved by the U.S. government for use by people with type 1 diabetes. Type 1 diabetes is a medical problem where the body does not make enough of the substance insulin, with the result that there is too much sugar in the blood. By the late 1990s, companies began to develop plants to produce other pharmaceuticals. In 2002, for example, corn containing a drug called aprotinin, which is used to reduce blood loss during surgery, was grown in a test field in Nebraska. That year the U.S. Department of Agriculture (a part of the federal government) issued permits for thirty-two tests of pharmaceutical barley, corn,

Words to Know

Biopharming: Growing genetically engineered plants or animals that produce drugs.

Diabetes: A disease in which the body cannot make or properly use the hormone, insulin.

DNA: A double-helix shaped molecule inside cells that carries the genetic information.

Insulin: A substance made by the body (or by genetically engineered bacteria) that the body needs to regulate the amount of sugar in the blood.

Pharmaceutical: A drug, medicine, or vaccine.

rice, and tobacco. In 2003, the company Epicyte began to test a drug for treating herpes (a sexually transmitted virus) that was grown in genetically engineered corn.

Current Issues

As of 2006 crops were still not being used to make drugs for sale. The main reason was that government officials and opponents of genetic engineering feared that genetically engineered crops might get mixed accidentally with food crops, and, as a result, unwanted drugs would get into food. In 2003, thousands of bushels of ordinary (non-genetically engineered) soybeans in Nebraska had to be destroyed after government inspectors found that genetically engineered pharmaceutical soybeans from the ProdiGene company had become accidentally mixed with the crop. Prodigene was fined $250,000 and had to pay $3 million in cleanup costs.

Critics of biopharming, including some scientists, also say that there is a chance—not large, but not zero either—that drug genes could jump from biopharmed plants to other plants. Supporters of biopharming say that the chances of such transfers happening are extremely small, and that by growing biopharmed crops apart from food crops the risk can be made even smaller.

Consumers in Japan and Europe are unwilling to buy genetically engineered foods. Many farmers in the United States are against biopharming because they believe that even if gene transfer or contamination of the food supply does not happen, they may be unable to sell their crops to foreign countries if biopharmed crops have been grown anywhere near them.

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[*See Also* **Vol. 2, Genetic Pollution; Vol. 2, Transgenic Plants; Vol. 2, Wheat, Genetically Engineered.**]

Polymerase Chain Reaction

Description

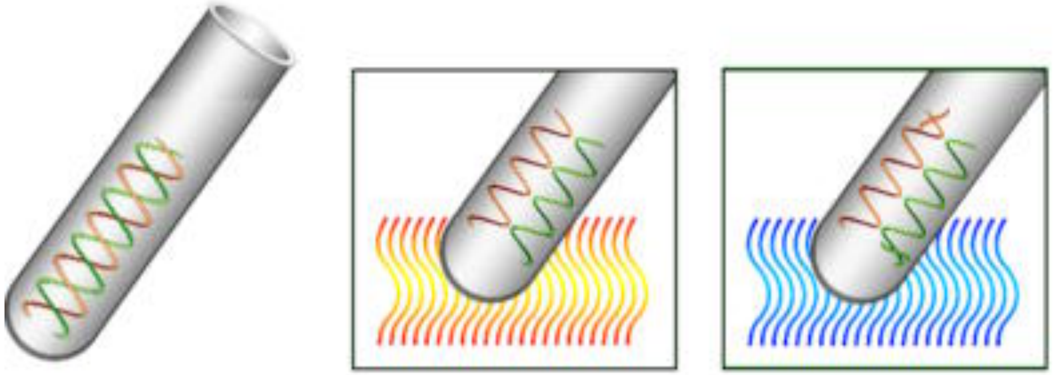
The polymerase chain reaction (PCR) is a way of making many copies of a piece of DNA quickly. DNA is the double-stranded chain of genetic information nearly every living cell. PCR is used in modern medicine, genetics, solving crimes, and other kinds of biotechnology. Without PCR, most of the advances in genetics made since the 1980s, including the Human Genome Project, would not have been possible.

In PCR, a DNA molecule of which copies are to be made is unzipped along its length—but not broken into shorter pieces—by raising it to just the right temperature, about 203 degrees Fahrenheit (95 degrees Celcius, a little less than the temperature of boiling water). Other chemicals are then used to build a complete, two-sided DNA molecule out of each of the one-sided molecules. These two double-sided molecules can also be melted and duplicated, making four double-sided molecules. Each time the process is repeated, the number of copies is doubled.

Four kinds of chemicals are used together in PCR. These are DNA template, free nucleotides (called "deoxynucleotides-triphosphate"), DNA polymerase, and primers. These chemicals (plus a watery buffer solution) are mixed together.

The DNA template is the piece of DNA to be copied. There may be one or many copies of the DNA template to begin with. The free nucleotides are raw material that will be used to build complete, two-sided DNA copies. DNA polymerase is a molecule that latches on to a one-sided DNA molecule and moves down it one nucleotide at a time, taking the correct nucleotide from the surrounding soup and attaching it to the growing two-sided molecule. DNA polymerases are found naturally in living cells. Finally, a primer is

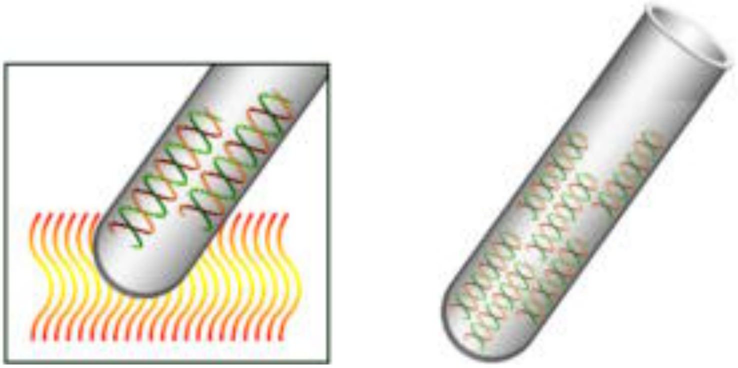
How the polymerase chain reaction works



DNA sample from blood or body fluid.

Temperature is raised to separate DNA strands.

Temperature is lowered and artificial DNA pieces are added.



Temperature is raised again, and the DNA pieces grow to create two complete copies.

This cycle is repeated to produce many copies of the same DNA to use in testing.

The polymerase chain reaction is used to copy a small sample of DNA many times. This makes genetic testing easier and quicker than in the past. *Illustration by GGS Inc.*

a short piece of one-sided DNA that matches the beginning or end of the piece of DNA to be copied. The primer sticks to the DNA template and tells the DNA polymerase where to start and stop working.

PCR is carried out in a machine called a thermal cycler. The thermal cycler raises the mixture of DNA template, nucleotides, polymerase, and primers to about 203 degrees Fahrenheit (95 degrees Celcius). This unzips the DNA template into one-sided molecules. The cycler then lowers the temperature of the mixture so that the primers can attach to the template, then raises it a little

Sorry, No Dinosaurs

In 1995, scientists announced that they had extracted DNA from dinosaur bones eighty million years old and amplified it using the polymerase chain reaction (PCR). People even thought that scientists might be able to bring dinosaurs back to life, as in the science-fiction movie *Jurassic Park* (1993). However, other scientists soon proved that the DNA was actually from humans, not dinosaurs, and had got into the PCR equipment by mistake. Yet scientists can and do study DNA that is up to two million years old. (Even frozen DNA breaks up when it gets older than that.) One exception might be a 2000 study that claimed to amplify DNA from a bacterium trapped in a salt crystal 250 million years old. But many scientists believe that this work is a mistake, just like the dinosaur DNA was in 1995. The bottom line: No DNA from dinosaurs has yet been found, and probably never will be. Even if it is found, scientists say it would be impossible to re-create dinosaurs, *Jurassic Park*-style.

so that the DNA polymerase can do its work efficiently. This cycle can be repeated many times.

Each time the process is repeated, the number of copies of the DNA template doubles. Starting with a single strand of DNA, after one cycle there are two copies of the strand. After two cycles there are four, and after four PCR cycles there are $2 \times 2 \times 2 \times 2 = 16$ copies. After thirty cycles there are 2^{30} or more than one billion copies. Because each complete cycle takes only about twenty minutes, hundreds of billions of copies of a single sample of DNA can be made in one day.

Scientific Foundations

DNA stands for deoxyribonucleic acid, the long molecule that controls heredity in all living things. Each molecule of DNA is shaped like a long, twisted ladder. The rungs of this ladder are small clusters of atoms called nucleotides. Each rung of the DNA "ladder" consists of two nucleotides weakly connected in the middle. DNA can also be imagined as a zipper, with its nucleotides locked together down the middle like the interlocking teeth of a zipper. DNA can be unzipped by certain chemicals or by heat. In PCR, heat is used.

Development

PCR was invented in 1983 by American biologist Kary Mullis (1944–). Mullis thought up the method while driving along a

Words to Know

DNA polymerase: A chemical that turns a single-sided piece of DNA into a double-sided piece. Found in nature and used in the polymerase chain reaction (PCR).

DNA template: In the polymerase chain reaction used to copy DNA, the DNA template is the piece of DNA that is to be copied.

PCR: Polymerase chain reaction. A method of making many copies of a short piece of DNA quickly.

Primer: In the polymerase chain reaction used to copy DNA, primers are short lengths of DNA that attach to the single-stranded DNA template and tell DNA polymerase where to start copying and where to stop.

Thermal cycler: A machine used to precisely heat and cool the mixture used in the polymerase chain reaction (PCR).

seaside highway in California one night. In 1993, Mullis received the Nobel Prize in Chemistry.

The DNA polymerase that was used in early PCR broke down during every cycle, destroyed by the heat, and had to be replaced. In the early 1990s, however, DNA polymerase was discovered in heat-loving bacteria called *Thermus aquaticus* that live naturally in geysers (jets of boiling water that come out of the ground in places such as Yellowstone National Park in Wyoming). This polymerase is now standard in PCR. Because it is not broken down by heat, there is no need to add new polymerase for every PCR cycle.

Current Issues

PCR has allowed DNA analysis to be used in many fields, including genetic fingerprinting, genetic engineering, detection of hereditary diseases, cloning, paternity testing (testing to determine who fathered a child), and the fast decoding of entire genomes, including the human genome. (A genome is the complete set of DNA molecules for a species.) Although there have been benefits from these technologies, many issues have also surfaced. Some people oppose genetic engineering, for example, because information about the DNA of individual people might be used to discriminate against them. PCR is basic to modern biotechnology, and biotechnology is a collection of tools that can be used both positively and negatively.

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[*See Also* **Vol. 1, DNA Sequencing; Vol. 1, Genetic Testing, Medical; Vol. 2, Recombinant DNA technology.**]

Retina and Iris Scans

Description

Retina and iris scans are methods for checking a person's identity. The retina and the iris are both parts of the eye. The retina is the back surface of the inside of the eyeball, where the image is cast by the lens. The iris is the colorful part of the eye that surrounds the pupil (the dark hole through which light enters the eye). The pattern of blood vessels in the retina is different in every eye.

The retina and the iris are both, like fingerprints, different for every person. Not even identical twins have identical eyes. A computer record can be made of the pattern of a person's retina or iris and compared later to the pattern of somebody claiming to be that person.

Retina and iris scans are more difficult to fool than fingerprint systems. Fingerprints can be made out of plastic, for example, and glued to a person's fingertips to fool an identification system. Retinas and irises are more difficult to copy, and they decay quickly after being removed from the body.

Retina and iris scans are used to control entry to high-security locations like nuclear weapons facilities. They are also sometimes combined with other biometric methods, that is, methods for exactly measuring features of human beings that are different for each person—fingerprints, the shape of the face, the shape of the hand, the way one walks, the sound of the voice, and more.

Scientific Foundations

The retina is covered with light-sensitive cells that send nerve impulses to the brain that correspond to the image focused by the lens of the eye. Like other body cells, the cells of the retina need

IRIS CAMERA

Airplane traveler undergoing an iris scan for airport security in Boston. © *AP/ Wide World Photos.*

oxygen and nutrients. These are supplied by a branching web of fine blood vessels. The exact pattern of these vessels forms in the eye in infancy and remains the same as a person grows up. No two retinas are exactly alike.

The iris is a circular arrangement of muscles and connective tissues. In dim light it relaxes to enlarge the pupil and allow more light into the eye, and in bright light it contracts, letting in less light. As with the retina, no two irises are exactly alike.

In iris or retina scanning, a digital camera first takes a picture of the eye. A mathematical model of the iris's or retina's pattern is then made and stored in computer memory. (A mathematical model of an object in the real world is a set of equations or other mathematical expressions that describes something important about that object.) Later, when a person's identity is to be checked, their eyes are scanned again and a new mathematical model is made. This is compared to the old one. If there is a match, the person is the same.

Development

Use of the retina for identification was first proposed in 1935, and use of the iris was first proposed in 1936. However, without computers it was not practical to use these methods.

Iris Scanning in Iraq

Iris scanning has been used by the U.S. military in its occupation of Iraq, which began in 2003. As of 2006, new members of the Iraqi military were being iris-scanned by the U.S. military using a tool called the Biometric Automated Toolset System or BAT. The BAT records not only people's irises but the shape of their face and their fingerprints. The BAT is also being used to track civilians. In late 2004, when refugees re-entering the Iraqi city of Fallujah, from which they had fled months earlier when it was conquered by the U.S. military, all men of military age had to submit to a ten-minute BAT inspection, including an iris scan, and be issued an identification card. The U.S. goal was to prevent anti-U.S. Iraqi fighters from re-entering the city posing as refugees. Many Iraqis were angry at having to undergo the scans before returning to their city.

The company EyeDentify was founded in 1975 and sold its first commercial retina scanner in 1985. In 1989, two eye doctors, Aran Safir and Leonard Flom, joined with Harvard physicist John Daugman to design an iris-recognition method. Daugman patented a method that is today used in all commercial iris-scan systems.

Today, airports in a number of countries are using iris identification systems. The U.S. Federal Bureau of Investigation (FBI), Central Intelligence Agency (CIA), and National Aeronautics and Space Administration (NASA) have all used retina scan systems to control access to sensitive locations.

Current Issues

Like all other biometric systems, retina and iris scan systems can and do make mistakes. Mistakes can happen when different lenses and lighting conditions are used to make the original record of the iris or retina, or if the head of the person to be identified is in a slightly different position.

Iris scanning is being used in some airports and other settings where speed is needed because it is quicker and less invasive than retina scanning. To make a retina scan, a machine must shine an infrared laser into the inside of the person's eye. To make an iris scan, a digital camera simply takes a picture of the front of the eye. Also, many people's retinas change later in life because of disease. However, tests have shown that iris scanners can be fooled by showing them a photograph of the eye. Contact lenses with a photograph of another person's iris embedded in them can also fool today's iris scan systems.

Words to Know

Biometrics:	Computerized identification of persons using traits or behaviors that are unique to each individual.
Iris:	Colored portion of the eye.
Retina:	An extremely light-sensitive layer of cells at the back part of the eyeball. Images formed by the lens on the retina are carried to the brain by the optic nerve.

Engineers hope to fix these problems in future systems. One way to make sure that an iris is real (and alive) is to vary the brightness of a light source and film the iris as it shrinks and expands to adjust to the light.

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[*See Also* **Vol. 3, Biometrics; Vol. 3, Fingerprint Technology; Vol. 3, Security-Related Biotechnology.**]

Security-Related Biotechnology

Description

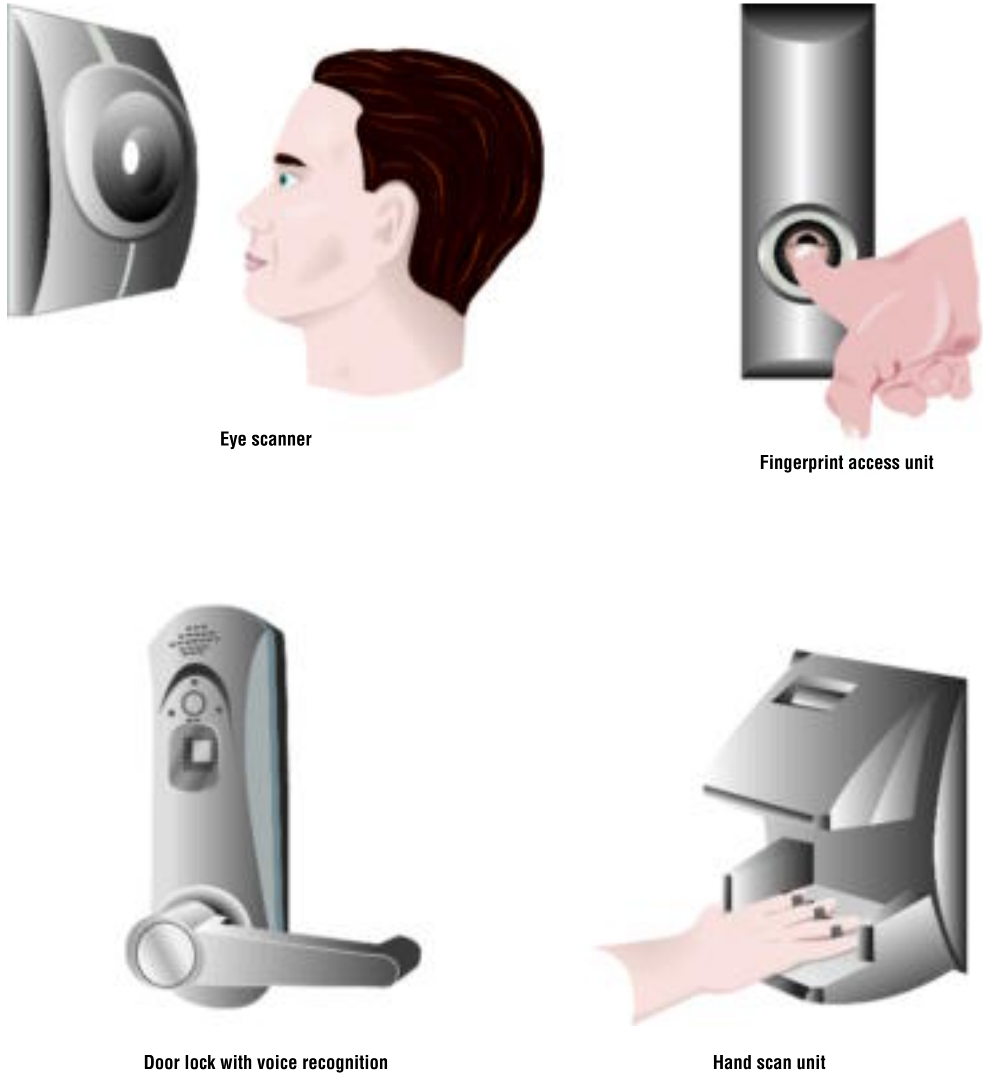
Security-related biotechnology refers to biotechnology techniques used to detect or respond to threats to individual and societal security. The threat posed by the deliberate contamination of food and water by a disease-causing (pathogenic) microorganism (like bacteria or viruses) is an example of a security issue. Biotechnology can detect the presence of pathogens in materials such as food and water by isolating regions of the pathogen's genetic material responsible for the production of a toxin (poison) unique to the microorganism.

Scientific Foundations

Identification of dangerous microorganisms involves first detecting the organism by its DNA. DNA is the double-stranded chain of genetic information held in nearly every cell. Complementary DNA is a single-stranded chain that is created in a laboratory. To identify a specific piece of DNA from a pathogen, the complementary piece of DNA is fixed to a solid surface and a solution containing the pathogen is added. If the target DNA from the pathogen is present in the added fluid, it binds with the complementary DNA. This allows the presence of the target pathogen to be detected.

Exposure to contaminants can also be discovered by detecting the presence of antibodies. Antibodies are proteins created by the body's immune system in response to the presence of a specific foreign protein (generically called an antigen). An antibody binds only to its specific antigen, and this binding prevents the antigen from working as it normally would (often to cause disease). To identify an antigen, its correlating antibody is attached to a surface and the suspected antigen is added. The binding between antibody

Security-related biotechnology



Eye scanner

Fingerprint access unit

Door lock with voice recognition

Hand scan unit

Four different types of biotechnology security devices, which rely on a person's identifying characteristics. *Illustration by GGS Inc.*

and antigen are revealed by a chemical change, like a change in the color of the solution. This is the basis of the enzyme-linked immunosorbant assay (ELISA) that is used to monitor food and water samples for the presence of pathogenic microorganisms.

Another biotechnology technique used in security is gel electrophoresis. In this technique, DNA is broken down into differently sized

Bioforensics

Biotechnology techniques used to detect and identify bacteria can be used as part of the forensic examinations that occur at the scene of a crime or following incidents such as the mailing of anthrax-tainted letters that occurred in 2001. Bioforensics can help pinpoint the origin of a microorganism, which can determine if its presence was the result of an accident or a deliberate contamination. Organizations such as the Federal Bureau of Investigation (FBI) in the United States, Interpol in Europe, and the Royal Canadian Mounted Police (RCMP) in Canada extensively use bioforensics in state-of-the-art laboratories.

fragments using specialized chemicals called restriction enzymes. The enzymes recognize and cut off certain pieces of DNA. The fragments are applied to the top of a material that allows the movement of the DNA fragments in the presence of an electric current, but allows smaller fragments to move more quickly than larger fragments. As a result, the DNA fragments separate from one another. The different fragments are collected and individually isolated or probed to reveal if a fragment contains a DNA sequence of interest (such as that corresponding to the production of a toxin). Moreover, the structure of DNA in fragments can be determined, which can be used to identify the contaminating microorganism. This is called DNA sequencing. DNA sequencing can also be done following the release of genetic material from microorganisms recovered from air, food, or water samples.

Development

Molecular techniques for the detection of harmful microorganisms, their components, and their products such as toxins have been usually developed for basic research purposes. The adaptation of these techniques for security arose in response to two main threats.

The first was the use of molecular biology to engineer harmful microorganisms. Although such research was carried out in the United States until being ended by then-President Richard Nixon (1913–1994), some countries, including Russia and Iraq, also engaged in bacterial weaponization research beginning in the 1970s. In that same decade, anthrax was deliberately released in Tokyo by a religious cult. These events highlighted the dangers posed by the malicious use of pathogens and at least indicated that there was a need for a rapid detection of harmful microorganisms.

Words to Know

Anthrax: A deadly disease caused by anthrax bacteria. Used more often as a biological weapon than any other bacterium or virus.

Biotechnology: Any technique that uses parts of living organisms to create or modify products, plants, animals, or microorganisms for specific uses.

Bioterrorism: Terrorism using biological weapons such as bacteria or viruses.

Complementary DNA: DNA that is created (transcribed) from an RNA template. This is the reverse of the normal process and so is called reverse transcription.

Enzyme: A protein that helps control the rate or speed of chemical reactions in the cell.

***Escherichia coli*:** *E. coli*, a species of bacteria that lives in the intestinal tract and that are often associated with fecal contamination.

Gel electrophoresis: A laboratory test that separates molecules based on their size, shape, or electrical charge.

Restriction enzyme: A special type of protein that can recognize and cut DNA at certain sequences of bases to help scientists separate out a specific gene.

Researchers were spurred to adapt detection technologies for national security after the U.S. Postal Service was used to deliver anthrax-laced letters to targeted individuals and organizations in the months following the September 11, 2001, terrorist attacks in the United States.

Scientists continue to refine the detection techniques for microorganisms to both expand the types of microbes that can be detected and increase the sensitivity of detection. In water samples, for example, it is possible to detect a single bacterium in a 100-milliliter volume of water. This is equivalent to detecting a single drop of water added to an Olympic-sized swimming pool.

Current Issues

Gel electrophoresis and DNA sequencing were used to determine that the same type of anthrax bacteria was used to contaminate letters sent through the U.S. Postal Service in the months immediately following the September 11, 2001, terrorist attacks on the World Trade Center and Pentagon in the United States. This implicated a single person or organization in the anthrax-laced letter terrorist incidents, although those responsible have not yet been identified.

With the rise of terrorism in America and abroad, the threat posed to food and water by the deliberate introduction of microorganisms has led to the need for increased protection of food and water supplies. Increased control of domestic sources and heightened scrutiny of national and international borders as well as a coordinated response to security breaches are required.

In one example, municipal surface water supplies can be fenced in to prevent the deliberate addition of harmful chemicals or biological agents to the reservoir. In another example, portable sensors have been developed that are capable of detecting the presence of disease-causing bacteria such as *Escherichia coli* O157:H7, based on the presence of signature bacterial antigens and even by the production of characteristic odors. These types of sensors are beginning to be used in food inspection and may become part of the inspection of foods at entry points into the United States.

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[*See Also* **Vol. 3, Biodetectors; Vol. 3, Fingerprint Technology.**]

Silk-Making

Description

Silk produced by spiders is the strongest natural fiber known to humans. It is stronger by weight than steel, yet is flexible and lightweight enough to make it an ideal component for a variety of fibers. Researchers are always looking for tough materials to use to make new products. The trouble is getting enough of it to make anything. Spiders cannot be farmed because they are very territorial and would likely attack each other.

Using biotechnology, scientists study how spiders make silk so they can create their own version. One way to make silk in larger quantities is by genetically engineering mammals (warm-blooded animals) with spider genes.

Scientific Foundations

Spiders spin their webs by secreting a protein that is very similar to keratin, the protein that gives hair its strength. (Proteins are substances produced by cells to control most of their functions; each protein does a specific task.) The protein is first mixed with water. As the mixture passes through a tube in the spider's body, the water is removed, creating a thick gel. When the spider releases the protein through a small hole in its body, the protein hardens into a very fine silk thread.

Genes control the production of the protein that gives rise to spider's silk. A gene is a segment of deoxyribonucleic acid (DNA) that provides the instructions for producing a specific protein. (DNA is the double-stranded chain of genetic information contained in nearly every cell.) Scientists can take genes from one animal and insert them into another animal to make it produce

Korean women making silk in 1946, by taking silk from silkworm cocoons and putting the thread on a loom. © *Horace Bristol/Corbis*.

proteins it would not make naturally. To produce spider's silk, scientists insert the gene for the spider's silk protein into a mammal's DNA. This process of manipulating DNA is called genetic engineering, and the animal that receives the new gene is called transgenic.

Development

The first products made from spider's silk—gloves and stockings—appeared in Paris in 1709. Since then, researchers have tried to copy the tough fabric without much success. In the 1960s, they attempted to make synthetic versions, but were unable to do so.

Scientists are now able to genetically engineer mammals to produce spider's silk. They first inserted the gene for the spider silk protein into hamster and cow cells. The cells were able to produce the protein, which was then extracted and spun into small amounts

Silk-Making Goats

Why would scientists focus on goats to make spider's silk? Because goats already contain the basic machinery for producing the silk proteins in their milk. Plus, a goat can make silk proteins in much larger quantities than a spider can. A single goat can produce about 1,000 quarts (950 liters) of milk per year. Each quart can contain between one and ten grams of spider's silk, a significant amount considering one gram can stretch 9,000 yards (8,200 meters).

of silk. To produce larger amounts, scientists needed to use a whole mammal. A biotechnology company in Canada, working with the U.S. Army, was able to insert the silk-producing gene in goat cells.

The company inserted the isolated spider gene into a goat's DNA at the embryo stage (an animal's earliest stage of development). The embryo was then transferred into the uterus (the female reproductive organ in which the baby animal develops before birth) of an adult female goat. When the genetically engineered goat matured and gave birth to its own young, the spider genes caused it to release spider silk proteins in its milk. Scientists were able to remove the liquid and isolate the spider silk protein. Then they pushed the protein through a tiny needle to form a silk thread like a spider would make.

Spider's silk has a number of potential uses, including the manufacture of rip-resistant and bulletproof clothing to protect policemen and the military; artificial limbs; and dissolvable stitches for surgery. It could also be used to repair tendons (strong pieces of tissue that connect muscle to bone) and ligaments (bands of tissue that connect the bones).

Current Issues

Scientists still have much to learn about spider's silk. They are trying to decipher the many genes responsible for silk-making. Each gene produces a different type of protein, and each protein is responsible for creating a different type of silk. Some silks are stronger than others. In 2005, scientists found the gene for the protein used to make the most elastic silk—the silk that spiders use to spin their egg cases.

Words to Know

Deoxyribonucleic acid (DNA): The double-helix shaped molecule that serves as the carrier of genetic information for humans and most organisms.

Embryo: A stage in development after fertilization.

Gene: A discrete unit of inheritance, represented by a portion of DNA located on a chromosome. The gene is a code for the production of a specific kind of protein or RNA molecule, and therefore for a specific inherited characteristic.

Genetic engineering: The manipulation of genetic material to produce specific results in an organism.

Ligaments: Structures that hold the bones of joints in the proper position.

Synthetic: Referring to a substance that either reproduces a natural product or that is a unique material not found in nature, and which is produced by means of chemical reactions.

Tendons: Strong pieces of tissue that connect muscles to bones.

Transgenic: A genetically engineered animal or plant that contains genes from another species.

Uterus: Organ in female mammals in which the embryo and fetus grow to maturity.

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[*See Also* **Vol. 2, Animal Cloning; Vol. 2, Genetic Engineering; Vol. 2, Genetically Engineered Animals; Vol. 2, Transgenic Animals.**]

Smart Materials and Sensors

Description

The ability to detect the presence of microorganisms—tiny living things such as bacteria or viruses—can be very important. Some microorganisms are disease causing (pathogens), while others can spoil food or drinks. For over a century, bacteria have been detected based on their ability to grow on a solid surface that is made of a material that the bacteria can use for food. While accurate, test results may not be known for days, as the bacteria need time to grow and divide over and over to form a visible clump of cells called a colony.

The ability to detect microorganisms like bacteria in a shorter time is very desirable. This is possible using "smart materials," solid surfaces to which are attached a variety of molecules that reveal the presence of bacteria. The attached molecules, which actually reveal the presence of the microoganisms, are called sensors.

Scientific Foundations

Smart materials rely on the chemical binding (attachment) of specific molecules to a solid surface like glass or plastic. One type of molecule that can be used are antibodies—substances that have been produced by the body's immune system in response to foreign matter (antigens). In the natural world, antibody production helps protect us from microorganisms that can cause infections. Scientists have also taken advantage of this reaction between antigens and antibodies to design smart materials.

Because there are a huge number of antigens, a huge number of different antibodies can be produced. But, the antigen-antibody reaction is very specific; a particular antigen will cause the production of

A Smart Bandage

The bandage used to cover a wound may one day be capable of diagnosing the nature of the infection. Researchers at the University of Rochester have been successful in utilizing a tiny sensor to determine if an infection is bacterial and to distinguish whether Gram-positive or Gram-negative bacteria are present. The sensor, dubbed a smart bandage, may be capable of downloading the diagnostic information to a physician's computer. According to the researchers, the result would be quicker diagnosis of the infection, which would enable a more effective treatment to begin earlier.

a particular antibody. By attaching a certain type of antibody to the solid surface, the surface can be designed to detect a very specific type of microorganism. For example, a smart material has been designed that detects only one type of bacteria called *Escherichia coli*, or *E. coli*.

Another type of molecule that can be attached to the smart material is deoxyribonucleic acid (DNA). DNA is a ladder-like molecule that contains genetic instructions for life. DNA technology has become so precise that pieces of DNA that contain particular genes can be generated. (A gene is a stretch of DNA that contains information for the production of a certain component.) In one design of smart material, genes are attached to the solid surface, and only specific pieces of DNA will be able to bind to a particular strand that contains the complementary arrangement of DNA. This allows the detection of these sequences of DNA from samples such as water and blood. Since hundreds, even thousands, of DNA fragments can be attached to a surface, many different DNA sequences can be detected from a single sample.

Development

Materials have been designed that detect the presence of specific bacterial components. For example, a support can have pits in its surface large enough for bacterial components to fit into. One bacterial component that is targeted is called lipid A. Lipid A is found in Gram-negative bacteria (bacteria like *Escherichia coli* whose surface is made up of two membranes). Lipid A is not found in Gram-positive bacteria (bacteria whose surface is made of just one membrane). In this smart material, a molecule present on the inside wall of the pit changes color when lipid A is present. This

Words to Know

Antibody: A molecule created by the immune system in response to the presence of an antigen (a foreign substance or particle). It marks foreign microorganisms in the body for destruction by other immune cells.

Antigen: A molecule, usually a protein, that the body identifies as foreign and toward which it directs an immune response.

Enzyme: A protein that helps control the rate or speed of chemical reactions in the cell.

Fluorescence: Emission of light at one wavelength in response to light at another wavelength. For example, a substance that glows visibly when exposed to ultraviolet light is fluorescing.

Glucose: A simple sugar that exists in plant and animal tissue. When it occurs in blood, it is known as blood sugar.

Gram-negative: Those cells that lose the color of the Gram stain after they are washed with an alcohol solution during the staining process.

Gram-positive: Those cells that retain the color of the Gram stain after they are washed with an alcohol solution during the staining process.

Phospholipids: A molecule consisting of a phosphate head and two fatty acid chains that dangle from the head; the component of the plasma membrane.

material is beginning to be used in medicine, since it is important to know if the bacteria causing an infection is Gram-negative or Gram-positive in order for the doctor to prescribe the correct type of antibiotic.

Another related smart material has been developed that can trap whole bacteria within surface-localized shells composed of phospholipids (a molecule made up of a phosphorus-containing group attached to a chain of fat; bacterial membranes contain phospholipids). Since part of a phospholipid is water-loving and another section is water-hating, the phospholipids tend to form spheres. The spheres are large enough to hold water in addition to bacteria, which allows the addition of water-based dyes and other chemicals that react certain ways if the trapped bacteria are alive or are producing certain compounds.

Yet another design of biosensor contains attached tubes that are made of carbon atoms. The diameter of the tubes can be only a few billionths of a meter; scientists refer to tubes this small as nanotubes. In one version of a nanotube smart material, the tubes' inner wall is lined with a material that can combine with a sugar called glucose. When this combination occurs, the chemical releases energy in the form of light (fluorescence). Detection of fluorescence reveals the presence of glucose. Even more, measurement of the intensity of fluorescence can indicate how much glucose is present. This smart material is being developed to monitoring blood glucose levels inside the body after injection of the nanotubes. Someday a diabetic may not need to take a blood sample to find his/her glucose level.

Current Issues

Materials and sensors that permit the medical identification (diagnosis) of infections or the monitoring of physiological conditions could improve health care. In the United States, for example, delays in diagnosing infections affects millions of people each year and adds over $700 million to the costs of health care delivery.

Smart materials and sensors are in the developmental stages as of 2006. Yet, their potential is clear. Some day the diagnosis and even treatment of infections may occur by means of implanted devices or surface coverings.

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[*See Also* **Vol. 1, Biochip; Vol. 1, Bioinformatics; Vol. 1, DNA Fingerprinting.**]

Solid Waste Treatment

Description

Solid waste refers to the unwanted, hazardous, or infectious nonliquid material that is left over from domestic, industrial, and medical processes. Solid waste such as radioactive material can be hazardous and needs to be properly handled, contained, and reduced as much as possible. Similarly, solid waste from hospitals may include infectious material that must be disposed of or destroyed in a controlled manner.

Scientific Foundations

The scientific basis for using biotechnology in solid waste treatment involves the biochemical breakdown of organic material. One aspect of this process is known as composting.

Microorganisms (those too small to be seen without a microscope) such as bacteria can use organic material as a food source. By breaking down a complex organic molecule, the component elements carbon, nitrogen, and phosphorus are made available for use in the growth and metabolism of the bacteria. The microbial degradation or breakdown of the waste reduces its volume and amount, making its disposal easier.

Development

Domestic waste is a tremendous source of solid waste. Millions of households in North America alone dispose of solid waste every day. The waste includes organic material such as leftover food; and toxic waste such as old medicines, paints, and batteries. Without some way to reduce the volume of this waste, there will eventually be no space in landfills to store the material.

One way to reduce the volume of solid waste is to divide the waste. Waste that degrades very slowly or not at all can be buried

Equipment at the Detroit Municipal Sewage Water Treatment Plant. Solid wastes are removed from sewage and treated separately. © *Ted Spiegel/ Corbis.*

in large piles called landfills. Hazardous or infectious waste can be incinerated (burned). Other, more degradable solid waste can be specially treated to help with decomposition or breakdown.

The use of microorganisms to break down solid organic waste, called microbiological degradation, has always occurred, but the modern techniques of molecular biotechnology have refined and quickened the decomposition processes.

Depending on the microorganism, solid waste degradation can occur in the presence of oxygen (aerobic) or in the absence of oxygen (anaerobic). Anaerobic degradation happens more often in a landfill because the garbage is not exposed to air. Anaerobic degradation takes longer than aerobic degradation because anaerobic bacteria tend to grow and divide much slower than aerobic bacteria. For example, the aerobic degradation of organic waste that occurs in a household compost pile can be accomplished in several weeks, whereas the degradation of wood in a landfill can require several decades. Household compost piles contain decayed plant matter that can be used as a fertilizer or soil conditioner.

Solid Waste in the United States

Paper, which accounts for 36 percent of the municipal solid waste in the U.S., is the most common solid waste. Plastic accounts for 11 percent.

These and other nondurable goods—things that are not designed to last a long time—make up approximately about one third of the volume of solid waste landfills.

Paper and many types of plastic can be recycled and reused. This would reduce the burden in landfills, since items like plastic bottles end up occupying a considerable volume, since they can be compacted but not broken into tiny pieces the way glassware can be. Landfills reach their capacity on the basis of the volume, not on the basis of the weight of trash present. By recycling paper and plastic, more volume is available for other solid waste that cannot readily decompose.

Besides aerobic and anaerobic microorganisms, the temperature requirements of the microorganisms can aid in solid waste treatment. As degradation proceeds, the temperature of the decaying material increases. This is easily seen when a compost pile is disturbed in chilly weather. Bacteria and other microorganisms that are best suited to milder temperatures do not operate effectively (and may even be killed) at the higher temperatures. However, these organisms are replaced by thermophilic (heat-loving) microbes that thrive at the higher temperatures, allowing for continued decomposition of the remaining organic waste.

Some types of toxic waste can be degraded. Bacteria obtained from the soil, or engineered by the transfer of a gene coding for an appropriate degradative enzyme, can use a variety of toxic materials as nutrients. Bacteria that degrade petroleum, gasoline, and polychlorinated biphenyls (PCBs, pollutants that were formerly used as a coolant) exist and have been used to clean up spills in soil and in fresh and salt water. A radiation-resistant bacterium called *Deinococcus radiodurans* can degrade some forms of radioactive material. It is being studied in connection with the disposal of spent (used-up) material from nuclear reactors.

Solid waste management has progressed from a federally unregulated enterprise in 1950 to a highly regulated and controlled practice in 2006. In 1950, typical methods of garbage disposal included burning in open-air dumps and feeding to swine. Reclamation or saving of useable items was rare.

In the mid-1960s the federal government enacted the Solid Waste Disposal Act, which was the responsibility of the U.S. Public

Words to Know

Compost: A mixture of decaying organic matter, such as manure and leaves that can be used as fertilizer.

Incinerator: An industrial facility used for the controlled burning of waste materials.

Organic: A term used to describe molecules containing carbon atoms.

Radioactive: The production of high-energy rays as a result of changes in the atomic structure of matter.

Sanitization: Cleaning or disinfecting to remove living material like germs.

Health Service. In the early years of this act, individuals such as Robby Robinson and Floyd Forsberg were hired to oversee solid waste disposal efforts in the states of Missouri and Minnesota, respectively. Their pioneering efforts greatly expanded the solid waste treatment program and brought in improvements such as the use of elimination of open-air dumps.

As more states enacted legislation to revamp solid waste disposal practices, the examples of Missouri and Minnesota became the norm across the country.

Current Issues

Research on solid waste treatment continues. For example, the use of microorganism-containing sprays on solid waste during waste collection has shown promise in accelerating the breakdown of organic waste and reducing the odors typically associated with solid waste. This system may make solid waste disposal more efficient and lessen the demand for landfill space.

As with other environmental applications of engineered microorganisms, the release of genetically modified microorganisms can be a concern. However, composting is an ancient and long-used means of solid waste disposal.

The burning of infectious material can be efficient, if done in specialized enclosed facilities that do not allow the fumes to vent directly outside. Such facilities are not found in every municipality or city, making the disposal of solid infectious and hazardous wastes difficult. Some communities have opposed the installation of infectious waste incinerators, fearing the consequences that might result if the incinerator malfunctioned. Thus, even though the technology for incineration of hazardous waste exists, its use can be controversial.

As the need for solid waste disposal grows, more landfills are being constructed. This can be of concern, particularly to those who live near the facility. The "not in my backyard" objection to solid waste treatment is an ever-present issue.

One way to lessen the burden of solid waste disposal is recycling. In 2006, many municipalities have recycling programs and even regional composting facilities. The use-once-and-throw-away philosophy that was the norm only a few generations ago is being replaced by the realization that conservation makes sense both environmentally and economically.

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[*See Also* **Vol. 3, Biodegradable Packaging and Products; Vol. 3, Biodegradable Packaging and Products; Vol. 2, Compost/Organic Fertilizers; Vol. 3, Wastewater Treatment.**]

Waste Gas Treatment

Description

Environmental pollution is one of the biggest threats to human civilization. Pollutants (substances that cause pollution) come in all forms—solids, liquids, and gases. Much of the pollution can be attributed to modern lifestyles. For instance, vehicles running on petroleum-based fuel (gasoline), smoking, gases released by most factories, and incinerators are only a few examples of sources of gaseous pollutants, also known as waste gases.

Various waste gas treatments have been developed to eliminate or reduce such waste gases. Bioactive treatment, a relatively new technology in cleaning waste gases, helps industries release clean gas into the environment. This treatment is effective in removing odors and harmful unstable compounds. Industries related to pharmaceuticals, sewage treatment, wastewater treatment, sugar, tobacco, oil, petrochemicals (oil and gas-based), paint, fragrances, slaughter houses, food and meat processing, and chemically created resins (used extensively in industry) use bioactive treatment extensively.

Scientific Foundations

The main purpose of bioactive and other waste gas treatments is to remove toxins (poisons) from gaseous pollutants. Bioactive treatments are carried out using equipment known as biofilters. A biofilter is typically a closed chamber containing a filter that facilitates multiplication of certain bacteria and other microorganisms. A thin film of moisture surrounding the filter hosts the microorganisms. These microorganisms (often bacteria) help remove toxins and other waste from gaseous pollutants. Waste gas passed through the chamber is exposed to these microorganisms

Gas flame at a burn-off tower for an oil refinery. This way of getting rid of waste gases contributes large amounts of harmful greenhouse gases to the environment. *Larry Mulvehill/Photo Researchers, Inc.*

that break down wastes into simpler components such as carbon dioxide and water. Waste gases are thus purified. The type of bacteria used in the filter depends on the waste gas to be treated.

The biofilter's closed chamber is usually made of wood or bark. These materials facilitate the growth of microorganisms in the chamber.

Other Waste Gas Treatments

An air cleaning method known as cycloning involves passing waste gas through an apparatus called a hopper. While the gas moves along a hopper, air flowing in a spherical manner is also forced through. Any dust particles hitting the cyclone slow down and, being heavy, fall to the bottom, where they are then eliminated. Cyclones are effective for fair-sized particles but ineffective for very fine dust.

Another treatment removes pollutants by burning waste gas. In this method, the gas may not be capable of burning without the addition of extra fuel. A downside of this treatment is that the extra burning fuel required to clean the gas may introduce new contaminants.

Absorption, yet another method of removing waste gases, involves passing the gas through a column of a liquid that can suitably absorb the contaminant.

Development

The concept of using biofilters was introduced in 1923. However, it was only in 1955 in Germany that biofilters were used for the first time to treat foul-smelling waste gases. Studies in the field of biofiltration increased in the 1960s, with Germany witnessing a mass use of biofilters in the 1970s. In the 1980s, biofilters and similar waste gas treatment devices were developed to treat toxic gases emitted from factories. By the 1990s, more countries started using biofilters based on Germany's success.

Industries in most countries use biofilters due to their many advantages. Biofilters are a cost-effective solution that does not require elaborate equipment or the use of chemicals. It can be designed either in a single layer or multiple layers based on the space available. If required, part of it can even be installed underground to save space.

Unlike other waste treatment options, biofilters release only nontoxic products and remove up to 90 percent of pollutants (provided they are in low concentrations). The microbes used to treat pollutants can be easily selected and maintained in the biofilter.

Until recently, biofilters were commonly used to control odors from wastewater treatment plants and composting sites. However, they are now being used for treating waste gases from many other sources. Nevertheless, their use in the United States is still limited.

Current Issues

Although beneficial, biofiltration has some drawbacks. One of the biggest disadvantages is the time microorganisms take to filter

Words to Know

Filter: Electrical circuitry designed to smooth voltage variations.

Incinerator: An industrial facility used for the controlled burning of waste materials.

Microorganism: An organism too small to be seen without a microscope, such as a virus or bacterium.

Pollution: An undesired substance that contaminates another system (air, ground, water, etc.).

Toxin: A poison that is produced by a living organism.

toxins from the gases. If the gases have a high concentration of chemical contaminants, the biofilter only works when installed in large open areas.

Biofiltration is a popular method for waste gas treatment. However, there is a marked difference between waste management policies of developed and developing nations. Substances legally considered waste in one country may not necessarily be treated as waste in another country. Consequently, some countries have the required waste gas treatments in place while others continue to release untreated toxic gases into the atmosphere. This is also true of different locations within a country. Metropolitan cities may have some standards for treating waste gases, whereas rural areas and smaller cities may follow an entirely different set of rules. A universal standard for treatment of gas pollution must be clearly defined for waste gas treatments to be effective and achieve their objectives.

Due to inadequate enforcement of waste gas treatment policies, industries in many cases do not implement biofilters or other equipment. On occasion, companies are not held accountable for the way their factories and other setups manage waste disposal. Lack of data also makes it difficult to gauge the actual effects of waste gas treatment policy implementation.

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[*See Also* **Vol. 3, Bioremediation.**]

Wastewater Treatment

Description

Billions of gallons of water are released from sinks, toilets, and showers every day. After it leaves homes and businesses, wastewater travels through the sewer system to return to a body of water such as a river or lake. But the water that leaves homes and businesses is not clean. It is called wastewater, or sewage, because it contains solid materials, such as leftover food, soap, chemicals, and human waste. These wastes often contain disease-causing organisms that could make people sick. The goal of wastewater treatment is to remove these organisms, as well as other pollutants and any solids from the water before it is returned to rivers, lakes, and streams.

Scientific Foundations

Bacteria (tiny, one-celled organisms, some of which can cause disease) are a key part of the wastewater treatment process. They contain special enzymes—substances that trigger the chemical reactions that enable the bacteria to break down organic wastes in the water. There are two types of bacteria: aerobic (which require oxygen), and anaerobic (which do not require oxygen). Aerobic bacteria are used to break down wastes in large public treatment plants. Anaerobic bacteria are used in the septic tanks (underground tanks in which wastewater is treated) that are found in the yards of many homes. Anaerobic bacteria cannot break down wastes as well as aerobic bacteria.

Development

When people lived in small groups of hunters and gatherers, waste disposal was not an issue. But as populations grew and people moved into cities and closer living spaces, sewage became

Sand and water filters working to treat and recycle sewage water for later use by citrus farmers for irrigation. © *Kevin Fleming/ Corbis.*

a concern. People began thinking about how to dispose of their wastes as far back as thousands of years ago. The ancient Greeks developed the first waste dumps around 500 BCE. Later, the Romans built sewers that carried their wastes to the river. Still, wastewater remained a big health concern.

In the Middle Ages, improperly dumped wastes led to the rampant spread of disease. In the mid 1800s, a cholera (an infectious disease that is spread through contaminated water) epidemic raged across the world. In 1854, an English doctor named John Snow discovered that the London cholera epidemic could be traced to a contaminated water pump in the city. His discovery helped pave the way for the modern sewer system. The first septic tanks appeared in the late 1800s. They were used to remove solids from wastewater before it was returned to rivers.

In the modern treatment process, wastewater enters a treatment plant. Large objects such as sticks, stones, or rags are filtered out to prevent damaging the filtration equipment. In the primary treatment stage, sand and grit are removed from the waste water. The remaining waste water is placed in sedimentation tanks. The solid wastes settle and are pumped out, and the lighter materials such as oil and grease rise to the top, where they can be skimmed off.

Rocket-fuel Producing Bacteria

In wastewater treatment plants, aerobic bacteria break down wastes. But scientists have found one type of anaerobic bacteria that not only breaks down wastes, but produces an unusual byproduct when it does so. Bacteria known as anammox bacteria eat up ammonia (a type of gas that is made up of nitrogen and hydrogen) in wastes. In the process, they release hydrazine—otherwise known as rocket fuel. Anammox bacteria are the only organisms on earth that can produce this chemical, and scientists still do not know how they do it.

The second step uses bacteria to break down the organic (carbon-based living organisms) materials in the wastewater. Because the bacteria used are aerobic, air is added to the tanks to stimulate their growth. In the final stage of the process, the remaining wastewater is taken to another tank, where a chemical called chlorine is added to kill off any remaining bacteria and any other harmful organisms. Then the clean water is released into a river, the ocean, or another body of water.

The solid wastes that were separated out of the wastewater early in the treatment process go through another step. They are put in large tanks called digesters. Inside the tanks, bacteria break down the waste, removing any possibly harmful organisms. The material that is left is either sent to landfills or used as fertilizer.

Current Issues

In the 1970s, the Clean Water Act set up standards for the amount of pollutants that can be released into the water. Although sewage treatment plants remove many of the harmful substances in wastewater, some pollutants, harmful bacteria, and nutrients are still released into rivers, lakes, and streams. Pollutants and bacteria can contaminate drinking water and possibly make people sick. Nutrients can cause the overgrowth of algae (microscopic plant-like organisms that live in the water) in lakes and rivers. These algae can choke off the oxygen supply to the fish and other aquatic animals living in the water, killing them. Environmental groups have asked the Environmental Protection Agency (EPA) for greater funding for wastewater treatment. They want to reduce the amount of pollutants that are allowed to be released into the water supply.

Words to Know

Aerobic reaction: Reaction that requires oxygen or that takes place in the presence of oxygen.

Algae: A group of aquatic plants (including seaweed and pond scum) with chlorophyll and colored pigments.

Ammonia: A chemical composed of molecues containing one nitrogen and three hydrogen atoms.

Anaerobic: Describes biological processes that take place in the absence of oxygen.

Bacteria: Microscopic organisms whose activities range from the development of disease to fermentation.

Enzyme: A protein that helps control the rate or speed of chemical reactions in the cell.

Organic: A term used to describe molecules containing carbon atoms.

Septic tank: An underground tank, usually outside of a home, in which bacteria are used to break down and treat wastewater.

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[*See Also* **Vol. 2, Compost/Organic Fertilizers; Vol. 2, Soil-Modifying Bacteria; Vol. 3, Solid Waste Treatment; Vol. 3, Waste Gas Treatment.**]

Yeast Artificial Chromosome

Description

A yeast artificial chromosome (YAC) is an artificially created system that allows large pieces of DNA to be cloned. Cloning of DNA is important to scientists doing DNA testing. In order to analyze a piece of DNA in the laboratory, the sample must be sufficiently large. Often, the sample obtained for testing is microscopic, and DNA in the sample needs to be replicated (multiplied) in order to analyze it appropriately. In order to multiply a DNA fragment, the selected DNA is placed in the YAC, where it is replicated along with other genetic material.

Scientific Foundations

DNA (deoxyribonucleic acid) is the molecule of hereditary information contained in nearly every living cell. Genes are sections of DNA that contain recipes (code) for the production of specific proteins. Chromosomes are the physical strands of DNA carrying genes. The YAC contains genes and other genetic elements that are necessary for replication (the manufacture of another copy of the chromosome). When present in a recipient yeast cell, the YAC undergoes rounds of replication as the cell grows and divides, creating more and more copies of the chromosome. A YAC differs from other cloning systems in that the artificial chromosome can accommodate a large amount of deoxyribonucleic acid (DNA), allowing large sections of genetic material to be cloned.

When a YAC is incorporated into a yeast cell, the yeast replicates the artificial chromosome along with its own supply of genetic material during cell division. This cycle can be repeated over and over again with successive rounds of replication, as a

Test tube of gel plugs containing recombinant human DNA in yeast artificial chromosomes. © *Klaus Guldbrandsen/Science Photo Library. Photo Researchers.*

collection of cells known as a colony forms on the surface of solid growth medium. Every yeast cell in a colony will contain the same set of DNA. A colony can be harvested and the DNA extracted.

Being able to clone such a large amount of genetic material can speed up the determination of the genetic sequence of the DNA of an organism. YAC allows the cloning of more than twenty times

A Graduate Student Accomplishment

The YAC was developed in the late 1980s by David Burke. At the time, he was a graduate student. Virtually alone, he developed the means to insert large stretches of DNA into the chromosome construct, figured out how to express the YAC in yeast cells, and prepared a series of YACs that together housed a sizable number of human genes. This work represented a huge leap in the ability to study the human genome.

Following the completion of his graduate studies, Burke accepted a faculty position at the University of Michigan Medical School, were he continued to tackle daunting and technically difficult projects. As one example, he was one of the leaders in the development of the DNA chip, which houses thousands of genetic sequences and which enables the study of gene activity.

Dr. Burke attributes his success to still being a child at heart. According to him, science is best done with an eleven-year-old child's sense of wonder and play.

the content of DNA than can be cloned using other systems such as the bacterial artificial chromosome. A bacterium can clone up to approximately 50,000 nucleotides (the building blocks of DNA). In contrast a YAC can clone 500,000 to 1,000,000 nucleotides. This cloning capacity is the reason that the YAC was an important part of the determination of the sequence of the human genome.

Development

The origin of the YAC dates back to 1987. The report describing the construction of the artificial chromosome also recognized the potential of the construct in cloning large regions of DNA. Other scientists immediately seized on the technique to undertake large-scale cloning.

YACs have been used to clone DNA from bacteria, plants, and animals, including humans. For example, one approach used in the Human Genome Project was to chemically treat human DNA in a way that chopped the DNA into fragments of varying lengths. The ends of each fragment were cut in such a way that there were overlaps between adjacent fragments. The different fragments were incorporated into different YACs and cloned to obtain analyzable amounts of each fragment. When the DNA sequence of each fragment was determined, the overlapping regions allowed the sequences to be fit together to generate the entire sequence of the intact human genome.

Words to Know

Chromosome: A thread-shaped structure that carries genetic information in cells.

Cloning: The production of multiple genetically identical cells or organisms.

Current Issues

YACs are being used to explore the significance of a region of the chromosome called the telomere. Long thought to be just an indicator of the length of a chromosome arm, evidence now suggests that a telomere may play an important role in cell aging.

Research also continues to widen the applications of YACs, and to refine the system so that larger regions of DNA can be successfully incorporated into the recipient yeast and cloned.

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